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# THE JOURNAL OF AGRICULTURAL SCIENCE

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## NOTES ON THE EXTRACTION OF MILK SUGAR FROM WHEY.

By HERBERT ERNEST WOODMAN.

(*Animal Nutrition Research Institution, the University, Leeds.*)

IN view of the efforts which are being made to secure increased production of cheese throughout the country, it is of importance that greater consideration should be given to the problem of the profitable utilisation of the whey, which results as a by-product of the cheese industry.

Whey on an average contains 6·5-7·5 per cent. of substance in solution, of which 60-70 per cent. is milk sugar. Its content of albuminoid substance amounts to roughly 1 per cent. and its fat content varies within fairly wide limits according to the method of cheese-making employed, the type of cheese (whole or skimmed milk) made and the efficiency with which the process is carried out.

The following figures give the composition of average samples of fresh whey:

		Fleischmann	Väth
		(from skimmed milk)	
Water ...	...	93·45 %	93·00 %
Fat ...	...	0·35 ..	0·09 ..
Sugar ...	...	4·00 ..	5·45 ..
Protein ...	...	1·00 ..	0·92 ..
Ash ...	...	0·00 ..	0·54 ..

The fat content may be as low as 0·04 per cent. in the whey resulting from the making of skimmed milk cheeses and as high as 1·35 per cent. in that obtained from the production of fatty cheeses.

Apart from its use for feeding stock, and where conditions are favourable, probably the most profitable method of disposal of whey is the manufacture of milk sugar, for supplies of which, previous to the war, this country was almost wholly dependent on the Continent. The extraction of the sugar is rendered a matter of difficulty owing to the presence in the whey of acids, lactic and acetic, of protein and of salts, especially those of the alkalies. By the action of the acids and salts, a portion of the milk sugar is converted, during the evaporation of the

whey, into a non-crystalline variety, and is consequently lost. The presence of protein leads to frothing during the concentration of the whey in the vacuum pans and is also liable to retard the crystallisation of the sugar at the later stage. It is of great importance that the final commercial product should be as free from nitrogenous constituents as possible, as the presence of proteins affects the keeping properties of lactose adversely.

*Swiss method of preparation of lactose.* Lactose has long been prepared from whey in Switzerland by a very simple, though wasteful, process. On the Alps, where the necessary fuel can be obtained cheaply, whey is evaporated over fires in "cheese-kettles." This process yields a residue of yellowish-brown and very impure sugar, known as "sugar-sand." This impure preparation is subsequently sold to the sugar refiners for purification.

Thorpe(1) gives the following details of the method. 50,000 litres of whey are directly evaporated to dryness. The residue (1250 kgs.) is dissolved in water at 65° in copper pans,  $\frac{3}{4}$ -1 kg. of alum is added and the liquid is filtered through animal charcoal. The filtrate is boiled down to the syrupy condition and allowed to crystallise on wooden rods. The yield is 55-60 per cent. of the crude sugar.

The main objection to this empirical method lies in the fact that decomposition of lactose in solution begins at temperatures above 70°. Consequently, any method which involves continued boiling of the whey must be uneconomical and result in a considerable wastage of sugar.

*Outline of German method(2).* To the whey is added dilute caustic soda until the solution shows only a weak acidic reaction. It is then concentrated in vacuum pans at 60-70° to about  $\frac{1}{10}$  its original bulk, when it contains about 60 per cent. of substance in solution. The concentrated whey is allowed to cool slowly and the lactose, which crystallises out, is separated from the mother liquor by means of the centrifuge. The yield of moist raw sugar is about 3.85 per cent. of the weight of whey employed or about 75 per cent. of the total sugar originally present.

On boiling the mother liquor for a short time, the protein coagulates. This is worked up into "Ziger" cheese, or is fed along with potatoes to swine. The filtrate is further evaporated and allowed to crystallise. This results in the separation of a further 0.5 per cent. of sugar, making in all an amount of crude sugar equal to 4.35 per cent. of the weight of whey, or about 85 per cent. of the total sugar in the whey. The residual mother liquor contains sugar, protein and mineral salts, including the phosphates of calcium and potassium. It finds application as a fertiliser.

The raw sugar is purified in the following manner: it is dissolved in about three times its weight of warm water (50°) in copper vessels and to the solution is added powdered bone charcoal and about 0.2 per cent. of acetic acid. After bringing to the boiling point, a little magnesium sulphate is added and the boiling is continued for several minutes. The solution is filtered from the sediment of phosphate and protein (which constitutes a valuable fertiliser when treated with sulphuric acid) and the clear filtrate is evaporated in vacuum pans at 65° till it contains about 65 per cent. of sugar. It is then allowed to crystallise in iron pans and the sugar is centrifuged from the mother liquor.

*Suggested modification of German method.* In the summer of 1918, when attention was being directed to the necessity for encouraging the production at home of certain products which, previous to the war, had been almost entirely imported by this country from foreign sources, it was suggested to me by Professor Crowther that it would be useful to carry out a series of preliminary trials on the preparation of lactose from whey. Accordingly, at convenient intervals during the progress of other work, a number of experiments were made with a view to testing the efficiency of the German method. The results given here are necessarily, under the circumstances, somewhat incomplete; but it was thought, however, that they might furnish information and data of a preliminary character which might prove of value, should a more comprehensive investigation of the subject be undertaken.

In the German method outlined above, it will be observed that no attempt is made to remove the protein from the whey at the outset, so that the first crop of sugar separates from a solution containing approximately 10 per cent. of albuminoid material. Trials were made in order to ascertain whether, by coagulating the protein from the whey before proceeding with the evaporation, the method were capable of improvement. A modification such as this might have beneficial results in several ways. The evaporation of the whey *in vacuo* should proceed without excessive frothing. The sugar should separate from the concentrated whey more readily and should, in addition, be less contaminated with protein. It seemed possible in this manner to increase both the yield and the purity of the product.

Against these advantages, however, must be set certain obvious disadvantages: 1. The extra cost of a process involving initial coagulation arising from the extra labour, fuel and plant required. 2. The loss of a certain amount of sugar carried down by the protein precipitate. 3. The danger of "caramelisation" of sugar during the coagulation



#### 4 *Extraction of Milk Sugar from Whey*

process, owing to the necessity of heating to fairly high temperatures in acidified solutions.

*Analysis of sugar fractions.* The lactose content was determined according to the Soxhlet<sup>(3)</sup> modification of the Fehling's reduction method. About 0.5 gm. of the sugar was dissolved in water and the albuminoid matter was removed by the addition of a few drops of lead subacetate solution. After taking out the excess of lead with sodium carbonate, the solution was filtered and made up to 250 c.c. 50 c.c. of the mixed copper reagent were heated to boiling in a beaker and 100 c.c. of the sugar solution run in. The mixture was once more brought to the boil and the boiling was continued for exactly six minutes. The cuprous oxide which separated out was filtered on to a Gooch crucible, ignited and weighed as cupric oxide. The sugar figures represent percentages of hydrated lactose ( $C_{12}H_{22}O_{11} + H_2O$ ).

The protein content of the sugar was determined by the Kjeldahl method. The protein figures were obtained by multiplying the nitrogen content by the factor 6.31. This factor is probably somewhat low, as whey also contains small amounts of "whey protein" with a factor 7.55. Determinations of inorganic matter were made by igniting weighed amounts of the sugar at a dull red heat. In one or two cases, it was also necessary to determine the amount of ether-soluble material. In every case, the estimation was made on material dried for a short time in a steam-oven.

#### TRIAL I.

2½ litres of whey resulting from the production of Wensleydale cheese were concentrated in a vacuum pan at a temperature of 60–65° to a volume of 250–300 c.c. The acidity of the whey was so slight, that it was unnecessary to add soda before proceeding with the evaporation. No great trouble was experienced with frothing. The concentrated whey was allowed to cool very gradually during a period of 24 hours to the ordinary temperature, and the milk sugar which crystallised out was filtered on to a Buchner funnel and subsequently dried in a vacuum desiccator over  $H_2SO_4$ . The yield of sugar was 87 gm. (3.18 per cent. of the amount of whey employed). It was only very slightly discoloured and gave the following results on analysis:

Crystalline lactose	...	88.42 %
Protein	...	3.75 ..
Ash	...	2.85 ..
Ether extract	...	1.70 ..

The large percentage of ether soluble material is explained by the fact that the fat was not separated from the whey previous to evaporation and was consequently carried down during the crystallisation process by the sugar. This would not, however, occur in actual factory practice, as the whey would be run through a cream separator before undergoing concentration. A portion of the sugar was extracted with ether and the percentage of lactose in the product was then found to be 93 per cent.

The mother liquor from the first crystallisation was next heated to 75° in the water bath for a few minutes and the coagulated protein was filtered off and well washed with warm water. The washings were added to the main bulk of liquid.

Yield of dried crude protein, 24.8 gm. (about 1 per cent. of whey).

After making the filtrate from the protein almost neutral by the addition of soda, it was further concentrated *in vacuo* at 65°. On cooling, a second crop of sugar separated out.

Yield: 10 grams (0.4 % of whey).

Composition:

Crystalline lactose	...	...	92.20 %
Protein	...	...	3.67 ..
Ash	...	...	3.70 ..

Appearance: slightly discoloured.

The mother liquor was again brought almost to neutrality with soda, evaporated to a syrupy consistency on the water bath and inoculated with a crystal of lactose. After standing 24 hours, a further 20 gm. (0.8 per cent.) of impure brown sugar crystallised out.

Composition:

Crystalline lactose	...	...	84.42 %
Protein	...	...	6.15 ..
Ash	...	...	9.10 ..

The residual brown mother liquor was analysed with the following results:

Lactose	...	...	9.25 grams
Protein	...	...	7.21 ..
Ash	...	...	7.20 ..
$\text{P}_2\text{O}_5$	...	...	1.50 ..
$\text{K}_2\text{O}$	...	...	3.01 ..

The figures indicate that the separation of the protein by coagulation of the concentrated whey after the removal of the greater part of the sugar was by no means complete.

## TRIAL II.

In this trial, the bulk of the protein was removed from the whey before concentrating *in vacuo*. As a preliminary, several trials were made in order to ascertain the best method of coagulating the protein, keeping in mind the fact that working at high temperatures would result in the decomposition of some of the sugar.

It was found possible, especially when dealing with sour wheys, to effect coagulation by heat alone at 85–90°. When working with fresh sweet whey, however, coagulation was brought about more readily and at a somewhat lower temperature in the presence of a little acetic acid. A sample of fresh Wensleydale whey was heated to 82° in a water bath, at which temperature no sign of coagulation was to be observed. On the addition of a few drops of acetic acid, however, the protein immediately separated out. In no case was the removal of protein anything like complete, due partly to a protective action exerted by the sugar in the whey.

The coagulation was carried out in the following manner: The whey was heated to 75° in a water bath and to it was added acetic acid (0.5 c.c. glacial acid to every litre of whey). At this temperature, the coagulation began and it was completed by raising the temperature gradually to about 82°.

An interesting observation was made in tests where acetic acid was replaced by phosphoric acid. Coagulation of protein occurred if only small amounts of phosphoric acid were added; if the amount of phosphoric acid were increased, however, coagulation was prevented altogether. In two tests with 300 c.c. of whey, 2 c.c. and 3 c.c. of 50 per cent. phosphoric acid were added respectively. In neither case was coagulation brought about even at the temperature of boiling water and the addition of a little acetic acid at this stage also failed to cause the separation of the protein.

The protein was removed from 2500 c.c. of fresh Wensleydale whey by the method outlined above. After filtering off the protein (yield 23 gm.) on a folded filter paper, the clear filtrate was made almost neutral by the addition of dilute caustic soda and evaporated to  $\frac{1}{10}$  its bulk in a vacuum pan at 65°. The sugar, which crystallised out on allowing the concentrated whey to cool slowly, was filtered off and dried on a porous plate placed in a vacuum desiccator.

Weight of crude sugar, 96 gms. (3.84 per cent. of whey).

The analysis of the dried sample gave the following results:

Crystalline sugar	...	93.65 %
Protein	...	2.15 ..
Ash	...	4.00 ..

After making the mother liquor almost neutral, it was further concentrated *in vacuo* at 65°. The sugar which came out on cooling was of a pasty nature and was separated from the mother liquor by means of the centrifuge. It was then washed with a little alcohol and the discoloured mass was allowed to harden on a porous plate. After powdering and drying, it was submitted to analysis,

Yield: 25 gm. (1 % of whey)

Composition:

Crystalline lactose	...	84.30 %
Protein	...	6.40 ..
Ash	...	9.12 ..

The mother liquor from this crystallisation failed to yield a third crop of crystalline sugar after being further concentrated.

### TRIAL III.

This was a repetition of Trial II with 2½ litres of another sample of Wensleydale whey. The following results were obtained:

1st crop.

Yield of crude sugar: 77 gm. (3.08 % of whey)

Composition:

Crystalline lactose	...	93.43 %
Protein	...	3.12 ..
Ash	...	2.72 ..
Ether soluble	...	0.45 ..

2nd crop.

Yield of crude sugar: 10 gm. (0.4 % of whey)

Composition:

Crystalline lactose	...	77.80 %
Protein	...	4.20 ..
Ash	...	17.75 ..

It was not possible to isolate a third crop of sugar in the crystalline state.

From these trials, it would appear that little is to be gained regarding yield and purity of sugar by initial coagulation of the whey protein. The sugar from Trials II and III contained very little less protein than that obtained from Trial I. The results of Trials II and III (especially of III) gave evidence of partial "caramelisation" of the lactose during

### Extraction of Milk Sugar from Whey

the coagulation process, as it was difficult to obtain more than one crop of sugar in the crystalline state. In Trial I, the sugar crystallised quite satisfactorily from the concentrated protein-containing whey and the subsequent coagulation of the protein was brought about readily at a fairly low temperature and without addition of acid.

#### TRIAL IV.

The details of working were altered somewhat in this test. To 2½ litres of fresh sweet whey were added 50 c.c. of Derby whey which had been allowed to sour. The mixture was heated in a water bath. The protein began to separate out when the temperature of the whey was 80–83° and the process was completed by gradually raising the temperature to 93° during a period of ten minutes.

The albuminoid matter was removed by filtration and the filtrate was neutralised by the addition of alumina cream. After shaking the mixture vigorously and filtering, the clarified liquid was concentrated to a volume of 500 c.c. in a vacuum pan at 60°. To the concentrated whey was added animal charcoal and the mixture was brought to the boil, 2 gm. of  $MgSO_4$  and 1 gm.  $Al_2(SO_4)_3$  were then added and the boiling was continued for three minutes. After filtering, the solution was clear and almost colourless.

The filtrate was further concentrated to about 200 c.c. *in vacuo* at 60° and the residual liquor was allowed to cool slowly. The lactose was filtered off on a Buchner funnel and washed with a concentrated solution of lactose. The sugar was then brought on to a porous plate and dried in a vacuum desiccator over  $H_2SO_4$ .

Yield: 80 gm. (3·2 % of whey)

Composition:

Crystalline lactose	...	96·20 %
Protein	...	1·50 ..
Ash	...	1·60 ..
Ether extract	...	trace

This method gives a sugar of very fine appearance and of greater purity than that obtained from any of the other trials. There is, however, an increased danger of partially "caramelising" the sugar during the process.

*Purification of sugar samples.* Tests were made with fuller's earth as a decolorising agent in the place of animal charcoal. Below 60°, fuller's earth only effected slight improvement of a brown lactose mother liquor: if the solution were shaken for about 10 minutes with a little

fuller's earth at a temperature of 70–75°, a marked improvement resulted on filtering. Under the same conditions, the turbidity of a solution of lactose crystals was removed.

At all temperatures, however, animal charcoal proved more efficient in this respect than fuller's earth. Alumina cream at the ordinary temperature also effected a slight improvement in the appearance of turbid solutions of crude sugar.

(1) 20 gm. of the first crop of fat-containing sugar obtained in Trial I were dissolved in 120 c.c. of hot water. After adding a little  $\text{MgSO}_4$  and fuller's earth, the solution was placed in a water bath at 70–75° for 10 minutes, during which time the flask was frequently shaken. The solution was filtered and evaporated *in vacuo* at 60°. On cooling, 15 gm. of sugar separated out, which when dried gave the following results on analysis:

Crystalline lactose	...	...	95.58 %
Protein	...	...	0.49 ..
Ash	...	...	3.45 ..
Ether extract	...	...	0.59 ..

Most of the protein and fat had in this manner been removed. The high ash content arose from having added more  $\text{MgSO}_4$  than was necessary.

(2) 50 gm. of the same sample of sugar were recrystallised by dissolving in 250 c.c. of warm water, adding animal charcoal, and after bringing the solution to the boil, a pinch of  $\text{MgSO}_4$  and 0.5 c.c. of glacial acetic acid. The boiling was prolonged for three minutes and the solution was then filtered and evaporated to crystallising point *in vacuo* at 60°.

Yield of sugar: 39 gm.

Composition:

Crystalline lactose	...	...	98.63 %
Protein	...	...	0.66 ..
Ash	...	...	0.61 ..

(3) 47 gm. of the first crop of crude sugar from Trial III were recrystallised in a similar fashion, using animal charcoal,  $\text{MgSO}_4$  and acetic acid. A yield of 37 gm. sugar was obtained, with the following composition:

Crystalline lactose	...	...	98.53 %
Protein	...	...	0.64 ..
Ash	...	...	0.44 ..

(4) 20 gm. of the same sample of crude sugar were purified by boiling the solution for three minutes with a little fuller's earth and  $\text{MgSO}_4$ . A yield of 14.5 gm. of sugar separated out from the filtered liquid, after

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concentration *in vacuo* and subsequent cooling. The dry sugar was analysed and gave the following results:

Crystalline lactose	...	...	98.84 %
Protein	...	...	0.34 "
Ash	...	...	0.49 "

(5) 15 gm. of the third crop of impure sugar from Trial I gave 10 gm. of recrystallised sugar after purification with the use of animal charcoal,  $\text{MgSO}_4$  and acetic acid. A great improvement resulted in both appearance and purity, the content of protein and ash having been reduced to 1.04 per cent. and 0.68 per cent. respectively.

*Iron content of commercial milk sugar.* The question arose as to whether, during the evaporation of the slightly acid whey in iron vacuum pans, any appreciable amount of iron would be dissolved. In order to settle this point, the iron content of whey after separation of the butter fat was determined and the same determination was carried out on the semi-solid crystalline mass, which was obtained on evaporating the same sample of whey to  $\frac{1}{10}$  its bulk in an iron vacuum pan.

The dry matter was determined first on a weighed amount of the sample. The residue was then ignited at a dull red heat and the last traces of carbon removed with the aid of a few drops of concentrated nitric acid. The amount of ash was determined.

About 0.1–0.2 gm. of the ash was weighed out and dissolved in a little dilute nitric acid. The volume was made up to 100 c.c. Into each of two Nessler glasses were pipetted 10 c.c. of 10 per cent.  $\text{HNO}_3$  and 5 c.c. of 5 per cent. potassium sulphocyanide. Into the one glass was then run 5 c.c. of the ash solution and the volume was made up to the 50 c.c. mark with distilled water. The latter was also added to the contents of the other glass until just short of the 50 c.c. mark and then a freshly made solution of ferrous sulphate (0.01 gm. Fe per litre) was added drop by drop from a pipette measuring to 0.01 c.c. until the pink colour in the first glass was matched. From the volume of  $\text{FeSO}_4$  solution added, the amount of iron in the sugar ash was estimated.

*Sample 1.* (Whey after separation of butter fat):

Dry matter	...	...	6.35 %
Ash	...	...	0.70 %
Iron	...	...	0.00005–0.0001 %

*Sample 2.* (After evaporation to about  $\frac{1}{10}$  bulk):

Dry matter	...	...	67.00 %
Ash	...	...	7.65 "
Lactose	...	...	46.84 "
Iron	...	...	0.00161 "

It will be seen that the original whey contains the veriest trace of iron. After evaporation to somewhat less than  $\frac{1}{10}$  the initial volume, the value of the iron content indicated that an extremely small and negligible amount of iron had been dissolved from the vacuum pan.

In conclusion, I should like to express my indebtedness to Professor Crowther, who not only suggested this work, but also offered helpful advice during the carrying out of the trials.

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## INVESTIGATIONS OF THE HAIR OF DIFFERENT BREEDS OF CATTLE.

BY DR JOSEF ČÁMEK.

*(From the Veterinary Institute and the Institute of Animal Industry at the Polytechnic High School at Prague. Director: Professor Theodor Kašpárek.)*

MANY authors, for example, Settegast, Pusch, Kašpárek, Kraemer and Rostafinski, have attempted to draw conclusions concerning age, quality and breed of cattle from the type of hair produced. Exact investigations of the length and other features of the hair are, however, rare in the literature. Bílek has recently made some investigations of this kind under the direction of Professor Kašpárek, and has estimated the relation between the medulla and the fibrous layer, and has shown that the cross section of the hair is sometimes circular and at other times elliptical in shape. As a result of his investigations he came to the following conclusions:

1. The hair of bulls has usually a thicker fibrous layer than that of cows. The cross section is different according to sex. The hair of a bull preserves its circular cross section more than does that of cows.
2. There is no relationship between the colour of hair and the development of the fibrous layer and the medulla, but exception must be made with white hair, which in both sexes has a medulla of greater diameter than coloured hair. White hair in all breeds of both sexes is flatter than coloured hair.
3. The hair of prairie and valley cattle has a more strongly developed fibrous layer than that of mountain cattle.
4. The nature and the form of the hair is closely connected with the breed of cattle involved.
5. The differences due to breed were investigated in the case of Montafon, East Friesland and Red Bohemian cows at the age of three months. The fibrous layer is less developed than in grown-up cattle, and the proportion of medulla to horny layer is decidedly increased. The increase in the latter with age is to be considered as a peculiarity of these breeds of cattle.

6. The relationship between the diameter of the medulla to the cortex, which is a characteristic of the original stock, remains unchanged, even when the animals are transferred to other countries, and is not influenced by insufficient feeding and selective breeding. It is supposed that the relation between the medulla and cortex in cross bred animals of two heterogeneous breeds shows the dominant or recessive characters just as much as other morphological or physiological characters.

7. There appears to be no fixed law which relates the diameter of the hair to the breed of cattle. At the suggestion of Professor Kašpárek, I have further investigated these questions, and have attempted to ascertain the length, width and ash content of hair in different animals according to their sex and breed. It is well known that in animals under civilised conditions many external circumstances influence the length of the hair. Pusch states that with a favourable stable temperature of 16-18° C. and good feeding and regular cleaning, smooth, glossy and short hair is produced. In the case of bad feeding the hair of young cattle is thick and long, even in summer. He observed, however, that the hair of young cattle was long and wavy when they were fed with whole milk. Further, it is known that the hair of bulls is rougher and coarser than the hair of cows of the same breed. Werner says that the long hair in well fed young animals of type breeds, with well developed skin tissue, always have long, soft and curly hair.

The influence of climate has also much to do with the character of the hair. In an unfavourable climate where animals graze during cold nights and are kept in the open air, coarse and long hair is produced. Animals which are at grass in the latter part of the autumn have longer and denser hair than animals of the same breed which are kept indoors. Kraemer observed that the coat gets longer, stronger, and more close in a cold, damp climate. On the other hand, a hot climate produces short and thin hair. It is well known that the coat which appears in spring is short and does not grow until the autumn. At this time the undercoat appears, by which the hair becomes longer and denser. This contradicts Schwalbe's assertion that the winter coat is not so dense as that in summer, and that the hair which grows in autumn is thicker and longer. Rostafinski has the same opinion, but does not think that the hair in winter is thicker. Schwalbe's observations were made on ermines in Sweden, where the summer temperature is low. His figures do not coincide with those of Rostafinski, who says that cattle have no undercoat at all in summer. This appears only in the autumn and is shed in the spring with change of hair.

According to Settegast, the length of hair is said to be different for different breeds of cattle. Well bred animals have fine, soft hair and fine skins. The diameter of the hair is diminished by breeding.

Concerning the ash content of hair, little is to be found in the literature. Ellenberger states that the ash content of ox hair is 4.6 per cent. of the undried hair. Certain statements will be found in the *Animal Hair Atlas* of Waldayer, who says that dry hair contains 0.5-0.7 per cent. of inorganic material, and that the darker hair is, in general, richer in iron.

#### EXPERIMENTAL.

The hair of the following breeds was investigated: Lowland animals, black chequered and red chequered Dutch cows, red chequered cows of East Friesland, shorthorn brown Alpine cattle, Montafons and Swiss breeds, shorthaired dark red Pinzgauer, Frontosus breed, roan coloured and light coloured Simmentaler cattle from Yenč and Smyřic in Bohemia. A large part of the investigations refers to crossbred animals of the Hanak red chequered country type from the district of Litton in Moravia. This breed has been crossed by bulls from Bern. The hair was collected in November, December and January, at which time the greater part of the covering hair had already developed. The animals were kept under the same conditions. The hairs were taken from the same parts of the body, fifteen centimetres under the withers. The diameter and length of the long hairs were measured in the intact condition. One hundred coloured hairs from each chequered animal were measured, one hundred white and one hundred red hairs were examined. The numbers given in the table are the arithmetical averages of one hundred measurements. As a control, the series of hairs were measured three times, and the arithmetical means compared. The difference amounted only to 0.3-0.8 mm. According to Bílek, the hair of adult cattle is fusiform in shape, but the hair of young cattle in conical, with the apex downwards. Hence the cross section varies along the length of the hair. For this reason the hair was measured at the point of maximum diameter. This point was about one-quarter to one-fifth of the total length of the hair from the root. In young cattle, however, the point is close to the root follicle. In the determination of diameter, fifty hairs were measured from each animal, and the arithmetical mean is given in the table. The measurements were made at a magnification  $\times 80$ .

For estimating the ash content a mixture of long and short hairs was employed. The hair was washed in alcohol, and after being dried, two to three grains were incinerated in a porcelain crucible: 93 determinations

of the ash content were made from 178 head of cattle. In consequence of the war only a few analyses from some breeds could be made. In one instance, for example, the Hanak breed, it was impossible to find a heifer between  $1\frac{1}{2}$  and 3 years of age. Only animals of 1, 4 and 10 years of age could be examined.

#### MEASUREMENTS OF THE LENGTH OF HAIR.

*The East Friesland Breed.* The average length of hair was:

- (a) Red hair: in four cows 2.58–3.15 cm.  
in six head of young cattle six months to two years old, 4.16–5.93 cm.

(b) White hair: the white hairs in the same animal were, with one exception, shorter than the red ones, 2.96–6.09 cm.

The length of both white and red hair reaches its climax in two years in Dutch red cattle.

#### *Dutch bred Cattle.*

##### 1. Black chequered.

	(a) black hair cm.	(b) white hair cm.
5 cows ... ..	1.98–3.05	—
1 cow, 7 years old ...	1.84	1.71
1 heifer, 2 years old ...	5.50	4.68
1 bull, 4 years old ...	3.82	3.30

##### 2. Red chequered.

	(a) red hair cm.	(b) white hair cm.
3 cows ... ..	1.98–2.90	—
1 cow, 4 years old ...	2.91	2.61
1 heifer, 2 years old ...	4.65	—
1 heifer, 1 year old ...	5.06	4.21
1 heifer, 6 months old ...	2.74	2.58
1 bull, 4 years old ...	3.49	2.10
1 bull, 2 years old ...	5.70	5.20

#### *Bernese Hanak Chequered Cattle.*

The average length of red hair in 15 cows was 2.12–3.33 cm.; for white hair 1.75–3.25. These 15 animals were arranged according to their age and the average length of hair compared.

*Hair of Different Breeds of Cattle*

	(a) white hair cm.	(b) red hair cm.
2 cows, 10 years old ...	2.47	2.80
1 cow, 8 years old ...	1.97	2.39
3 cows, 6 years old ...	2.56	2.99
6 cows, 5 years old ...	2.84	2.86
2 cows, 4 years old ...	—	3.22
1 cow, 3 years old ...	2.62	3.10
1 cow, 1 year old ...	3.80	3.92
1 cow, 6 months old ...	4.35	4.99
1 heifer, 4 months old ...	4.21	4.31
1 bull, 4½ years old ...	4.15	4.91
2 steers, 1 year old ...	6.65	7.19
1 steer, 6 months old ...	5.29	6.16
2 steers, 3 months old ...	2.87	2.97-3.78
1 steer, 3 weeks old ...	2.96	3.46

*Simentaler Breed.*

	(a) white hair cm.	(b) fair hair cm.
2 cows ... ..	—	3.26
1 heifer, 15 months old ...	—	4.78
1 steer, 15 months old ...	—	5.02
1 heifer, 2 years old ...	—	4.52

The white hairs were shorter than the red ones. The longest hairs were in a steer and in a heifer, both 15 months old. The hair of the steer was longer than that of a cow of the same age.

*Montafon Breed.*

	cm.	on an average	cm.
10 cows ... ..	2.27-3.30	..	2.83
3 heifers, 2 years old ...	2.41-3.94	..	3.70
2 heifers, 18 months old ...	4.27-4.63	..	4.45
2 heifers, 1 year old ...	4.56-4.91	..	4.76
2 heifers, 6 months old ...	4.27-4.40	..	4.34
2 heifers, 3 months old ...	3.09-3.20	..	3.15
4 steers ... ..	2.41-3.94	..	3.19
2 oxen, 6 years old ...	2.40-3.20	..	2.72

*Swiss Breed.*

The length of the hair varied between 2.26-3.08 cm. in 6 cows; in a steer 2 years old it amounted to 3.96 cm. The hair of the steer was longer than that of the cow.

*Pinzgau Breed.*

The average length in 3 cows was 1.86-2.93, in a heifer 3 years old it was 3.85 cm.: therefore the heifer's hair was longer than that of the older cows.

The results of the measurements of the hair length lead to the following conclusion:

With the exception of one animal, the white hair in all chequered cattle was shorter than the coloured hair. The hair in pure bred cattle reaches its maximum length at the age of two years and six months, irrespective of colour and sex. With increasing age the hair becomes shorter. The hair of bulls is always longer than that of cows of the same age. The length of hair in oxen is the same as that of cows.

The differences in length found with different breeds of cattle is great. In well-bred young cattle the greatest length is found between the ages of one and two years. In ill-bred cattle the maximum growth of hair occurs between six months and one year. Young cattle have notably longer hair than older beasts.

#### THE THICKNESS OF HAIR.

##### *In East Friesland Breed:*

	(a) white hair	(b) red hair
Heifers, 6-18 months old ...	84.1-91.2 $\mu$	80.5-93.9 $\mu$
Heifers, 2 years old ...	84.8-95.4 $\mu$	94.6-96.7 $\mu$
Heifers, 3 months old ...	58.0 $\mu$	71.4 $\mu$

##### *In Dutch Breed, red and black:*

	(a) white hair	(b) red hair
Cows, of various ages ...	65.4-91.5 $\mu$	66.9-95.4 $\mu$
Heifers, 2 years old ...	91.4 $\mu$	106 $\mu$
2 steers ...	61.0-88.8 $\mu$	97.6-111.9 $\mu$
1 steer, 2 years old ...	90.9 $\mu$	120.2 $\mu$

##### *In Bernese Haubak chequered (diameter):*

	(a) white hair	(b) red hair
Cows, 6 months-10 years old ...	76.9-109.2 $\mu$	79.8-105 $\mu$
Bulls, 6 months-4½ years old ...	90.2-97.3 $\mu$	91.2-103.4 $\mu$
Bulls, 3 months and 3 weeks old ...	71.5-75.2 $\mu$	73.0-76.9 $\mu$

##### *In Simmentaler Breed:*

	(a) white hair	(b) coloured hair
Cows, 1½ and 10-13 years old ...	—	68.6-91.5 $\mu$
Heifers, 2 years old ...	107.4 $\mu$	115.7 $\mu$

##### *In Montafon Breed:*

	(a) white hair	(b) red hair
Cows of two different ages ...	74.1-111.6 $\mu$	average 97.2 $\mu$
Cows of 3 months ...	65.0-65.3 $\mu$	.. 65.2 $\mu$
Oxen ...	91.5 $\mu$	.. 91.5 $\mu$
Steers ...	82.4-112.0 $\mu$	.. 103.0 $\mu$

*Swiss Breed:*Cows, 76.7-98.2  $\mu$ .1 steer, 2 years old, 104.9  $\mu$ 

This last animal was noted as having the thickest and longest hair of the series.

*Pinzgau Breed:*

The thickness of the hair of this breed of animals was 80.6-102.8  $\mu$ . Young cattle up to three months have the thinnest hair. Above three months the hair has as great a diameter as that of adult animals. Bulls have, as a rule, thicker hair than cows or heifers of the same age. The stoutest hair is to be found in animals between one and two years of age of both sexes. White hair is relatively thinner than the coloured hair of the same animal.

## THE RELATION OF DIAMETER TO LENGTH OF HAIR.

Table showing the relation of diameter to length expressed in percentage.

Breed	Sex	Age	White %	Red %	Fair haired brown	Greyish brown	Black %
East	Cows	—	—	0.29-0.33	—	—	—
Friesland ...	Heifers	2 years	0.16-0.19	0.16	—	—	—
	Heifers	2 years	0.16-0.19	0.16	—	—	—
	Young cattle	1½ years	0.20-0.32	0.18-0.28	—	—	—
Dutch ...	Cows	—	0.78	—	—	—	0.30-0.44
	Heifers	2 years	0.21	—	—	—	0.20
	Steer	—	0.29	—	—	—	0.28
	Steer	—	0.13-0.28	0.15-0.28	—	—	—
Bernese Hanak	15 cows	—	0.28-0.48	0.27-0.72	—	—	—
	Young cattle	—	0.20-0.22	—	—	—	—
	Steers	—	0.15-0.27	0.14-0.26	—	—	—
Montafon ...	Cows	—	—	0.28-0.46	—	—	(average) 0.36
	Heifers	—	—	0.17-0.29	—	—	0.21
	Oxen	—	—	0.37	—	—	0.37
	Steers	—	—	0.28-0.33	—	—	0.30
	Steer	—	—	0.26	—	—	—
Swiss ...	Cows	2 years	—	0.27-0.38	—	—	—
	Steer	—	—	0.26	—	—	—

The results in the above table show that there is no regular relation between diameter and length. The longer hair is, as a rule, thicker and stouter. In short hair the diameter is proportionately greater than in long hair. In the hair of bulls we find lower figures than in that of cows and heifers of the same age. The same may be said concerning the hair of oxen. The percentages found with white hairs are higher than with coloured hairs.

## ASH CONTENT OF HAIR.

In these investigations cut hair was used, consisting of long and short hair. The unwashed hair gave two to three times the amount of ash found in washed hair. Ninety-three analyses were performed on hair selected from two hundred animals, with the following results:

Breed	Number and sex	Age	Colour	Content of ash %
East Friesland	8 cows	—	red hair	2.68-2.69
	2 heifers	2 years	red hair	2.52
			white hair	1.85
				2.37
	4 heifers	1 year	red ..	2.37
Dutch ... ..	8 cows	—	white ..	1.65
			black ..	2.83-3.05
			white ..	2.08-2.35
	4 heifers	2 years	black ..	3.02-3.36
			white ..	1.87-2.02
	6 heifers	1 year	red ..	2.75
			white ..	2.26
	2 steers	2 years	red ..	2.82-2.95
			white ..	2.26-2.52
Simmentaler	12 cows	—	fair ..	1.99-2.13
			white ..	1.79-1.86
	4 cows	4 years	brick red hair	2.27-2.35
			white hair	1.77-1.86
	6 cows	9-15 mths.	fair ..	1.92-2.02
			white ..	1.78-1.90
	3 steers	9-15 mths.	fair ..	2.13-2.38
			white ..	1.98-2.04
Bernese Hanak	30 cows	4-10 years	red ..	2.37-2.71
			white ..	1.74-1.85
	10 heifers	1 year	red ..	1.98-2.07
			white ..	1.42-1.50
	8 steers	1 year	red ..	2.03-2.08
Montafon ...			white ..	1.75-1.83
	16 cows	—	white ..	1.75-1.83
	10 cows	10 years	brown hair	2.28-2.36
	2 heifers	2 years	.. ..	2.16-2.59
	2 heifers	6 months	.. ..	2.17
				2.18
	4 steers	2-4 years	.. ..	2.41-2.88
	2 oxen	6 years	.. ..	2.21
Swiss ...	12 cows	—	.. ..	2.26-2.32
	3 steers	2-4 years	.. ..	2.52-2.74
Pinzgau ...	18 cows	—	red hair	2.78-3.11

No white hair was available for investigation. The above table shows that the ash content of hair is not characteristic for a given breed. The hair of brown animals has about the same ash content as the red hair



of chequered breeds. White hair is, on the whole, less rich in inorganic material than coloured. The more intensely coloured hairs contain the greatest proportion of ash. Comparing animals of different chequered breeds according to the intensity of colour, the following results were obtained:

	Content of ash %
Light Simmentaler	1.99-2.13
Light to dark red chequered breeds Bernese Hanak	2.37-2.71
Dark red East Friesland	2.68-2.69
Black Dutch	2.83-3.05

Similar results are obtained in comparing the content of ash in young cattle and bulls. The hair of heifers of the brown breeds show more ash than the more intensely coloured hair of cows. The hair of bulls of all breeds is richer in ash than the hair of cows of the same age. This is also found in the white hair of bulls. The hair of oxen has the same amount of ash as that of cows. There is no difference between the ash content of hair of cattle of one to two years of age and those that are older.

#### SUMMARY.

1. The maximum length of hair in pure bred animals is found between the ages of six months and two years. Older animals have shorter hair. The hair of bulls is always longer than that of cows and oxen of the same age. In a given animal the white hairs are shorter than the coloured ones. There is a large variation in the measurements of the coloured hairs in an individual animal. No relation was found between the type of fodder and the length of hair.

2. Young cattle up to the age of three months have the thinnest hair. After this period the stoutness of the hair is the same as that of adult animals. A maximum is reached in animals between one and two years of age of both sexes. Bulls have always thicker hair than cows and heifers of the same age. The white hair of a given animal is thinner than that of the coloured hair. Food is without influence on the stoutness of the hair. As a rule the thickness of hair increases with length.

3. The relation of thickness of hair to length is not always the same. With short hairs the diameter is relatively greater than with long ones. With bulls the ratio  $\frac{\text{diameter}}{\text{length}}$  is smaller than in heifers and cows of the same age. The ratio is greater with white hair.

4. The ash content of hair is not constant. It depends on pigmentation, age, sex, and possibly on feeding. The ash content of intensely coloured hair is the greatest. This hair also contains more iron than

white hair. Ash content is greatest with black hair. The hair of brown animals leaves the same inorganic residue as red hair. There is no difference to be found between the ash content of the hair of bulls and that of cows and oxen of the same age. The hair of young cattle contains less ash than that of full-grown beasts. After one to two years of age there is no difference to be found between these cattle and those that are older. Lack of food seems to lessen the amount of ash in the hair.

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# THE WASHING OUT OF NITRATES BY DRAINAGE WATER FROM UNCROPPED AND UNMANURED LAND.

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(Based on analyses made by the late N. H. J. MILLER.)

## *General Account.*

IN 1870 Lawes and Gilbert constructed the famous drain gauges at Rothamsted and commenced a series of measurements of the amount and nitrate content of water draining through uncropped and unmanured land. The essential feature of the experiment, and one wherein it differs from many others, is that the soil in the gauges is in its natural condition and has never been disturbed: the gauge was constructed by building a wall around a block of soil and then tunnelling underneath to allow of the construction of a chamber in which the collecting and measuring cylinders could be set up.

The soil receives no manure and it grows no crop, not even weeds being allowed; it is kept sufficiently hoed to maintain a clean surface.

From the outset the whole of the water percolating through the gauge has been measured. Since 1877 systematic determinations of the nitric nitrogen and chlorine in the drainage water have been made, at first by R. Warington, and from 1887 to Dec. 1915 by N. H. J. Miller. Two accounts have been published, one by Lawes, Gilbert and Warington in 1881<sup>1</sup>, and the other by Miller in 1906<sup>2</sup>. In the present paper it is proposed to give the rest of Dr Miller's data, obtained subsequent to the publication of his paper, and to review the whole of the results that have been obtained.

In any long continued series of measurements the question of the validity of the analytical data is of preponderating importance. Even small errors if they persist lead ultimately to large errors in the final results, and there is always the tendency for errors once in to continue.

<sup>1</sup> *Journ. Roy. Ag. Soc.*, 1881, 42, pp. 269 and 311.

<sup>2</sup> *This Journal*, 1906, 1, pp. 377-399.

Fortunately in this case two controls are possible, and they both show that a high degree of credibility attaches to the results.

Broadly speaking the results show that uncropped land steadily and persistently loses nitrogen in the form of nitrates. This of course was known. The unexpected feature is the slowness with which the soil loses the power of producing nitrates from its own stock of nitrogenous compounds. At the beginning of the experiment the soil contained 0.146 per cent. of nitrogen, about 3500 lb. per acre in the top 9"; it yielded up about 40 lb. of nitrogen per acre per annum to the drainage water. At the end of nearly 50 years it still contains 0.099 per cent. of nitrogen or 2380 lb. in the top 9", and it still gives up to the drainage water 21 lb. of nitric nitrogen per acre per annum, enough to produce a 15 bushel crop of wheat, although neither manure nor crop residues have been added during the whole of the period. If the curve (Fig. 2) showing the rate of fall continued its present course and without further slowing down no less than 150 years would be needed for exhaustion of the nitrogen.

So far as can be ascertained the nitrogen lost from the soil appears wholly as nitrate in the drainage water. From the top 9" of the 20" and 60" gauges the nitrogen lost has been respectively 1121 and 1172 lb. per acre. The nitric nitrogen in the drainage water amounts to 1247 and 1200 lb. per acre in the two gauges. These figures are arrived at by adding together the whole of the nitrate found and such estimated amounts as are possible for the first seven years before regular determinations were made, deducting nitrogen introduced by the rain. The subsoil is left out of account, but evidence is adduced to show that it contributes little if anything to the nitrate in the drainage water. Two items admittedly lack precision, being estimates only, but they are based on reasonable grounds and are probably not far wrong.

The figures agree as closely as could be expected. There is no sufficient deficit to necessitate the assumption of any other source of loss; we are not, for example, compelled to suppose any evolution of gaseous nitrogen or nitrogen compounds. Nor, on the other hand, is there any excess of nitrogen in the soil that would compel the assumption of nitrogen fixation. It is of course possible that both fixation and evolution of nitrogen occur in amounts that approximately balance, but the experiment fails to show either action.

Another remarkable result is the close relationship between the amount of nitric nitrogen in the drainage water and the amount of rainfall. In years of high rainfall large amounts of nitrate are washed out; in years of low rainfall the quantities are less (Fig. 1). The effect of a wet

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year persists and shows itself in a reduced capacity for nitrate production in the following year. The effect of a dry year also persists, there being a larger rate of loss in the following year. Most of the washing out of nitrate occurs during the months October, November, December and January: with the exception of the latter, these are also the months when the rainfall is highest (Fig. 3). On an average over the whole year, however, one inch of rain has for the past 25 years washed out 1 lb. of nitrogen, and for 15 years before that it washed out 1.1 lb.: only in the last 6 years is there any distinct sign of falling off.

It is difficult to account for this steady rate of washing out of nitrate from the soil in natural conditions. The nitrate behaves as if it were soluble only with difficulty. Under laboratory conditions, on the other hand, it is easily washed out by 2 or 3 inches of water from soil on a Buchner funnel. Some allowance must be made for the difference between soils *in situ* and soil loosely but evenly packed in a Buchner funnel. But there is clearly a tendency for nitrate formation to increase in a wet season, or else for incomplete removal of nitrate in normal seasons with consequent carry-over to the wet season when all nitrates are washed out.

The effect of temperature is less obvious, and can only be observed after the effect of rainfall has been eliminated by setting out the curves so as to show the amount of nitrate washed out per inch of rain. Unfortunately soil temperature records are not available over the period, but recent work shows a close connection between sunshine and soil temperature, and the sunshine records extend over a considerable part of the period. A relationship is seen between the nitrate in the drainage water and the sunshine of the preceding summer (Fig. 5). The sunshine effect and therefore the temperature effect, however, is distinctly secondary to the rainfall and is not easily seen excepting in this way. If there has been abundant rainfall from October to March there is likely to be a good deal of nitrate in the drainage water, and the amount will be raised still further if there has also been abundant sunshine in the preceding period between May and October.

It is difficult to account for the slow rate of loss of nitrogen on the currently received ideas of the nitrogen cycle in soils. There is no evidence of nitrogen fixation in the gauges: apparently the nitrate in the drainage water arises from the stock of nitrogen compounds originally present in 1870. These original nitrogen compounds would decompose giving rise to ammonia, which is then converted into nitrate, and some would break down more rapidly than others. But if nothing beyond

hydrolysis were concerned the process ought to have been completed many years ago. Some of the compounds would go more quickly than others, but even if we suppose any so resistant that they took respectively 46, 47, 48, 49 and 50 years to decompose the curves ought to show a less regular and a more broken downward trend.

In order to account for the phenomena it seems necessary to introduce into the ordinary cycle some new element acting as a kind of immobiliser, absorbing nitrates or ammonia as they are produced and giving them up again later on. The case would be met if one supposed that some of the soil organisms, such as algae, bacteria, fungi, etc., assimilated nitrates or ammonia and on their death were themselves decomposed, giving rise ultimately to nitrates again. On this view the nitrogen compounds of the soil would be supposed to break down with formation of ammonia and then nitrate, but only a portion, and not the whole, of this nitrate is liable to loss or assimilation by plants; the remainder would be taken up by organisms, temporarily immobilised, but reformed on the death and dissolution of the organisms, when again part would be thrown out of the cycle and part reabsorbed.

The curve showing the rate of washing out of nitrate from the soils of the drainage gauge is very different from the curve for the rate of accumulation of nitrate in soils under fallow conditions as seen in Fig. 6. In the open field nitrate production is rapid in May and June; then it falls off in speed, though it still continues right through the summer till autumn; the gains tend to exceed the losses so that the curve resumes its upward move after any falling off. The highest accumulation even on the unmanured plot in a fallow year amounted to 69 lb. per acre in the top 18". During the winter months, however, the losses exceed the gains: there is insufficient formation during this period to counteract the washing out, and the soil is left at the end with about 40 lb. per acre in 18", the minimum of nitrate normally found in our experiments. The loss therefore exceeds 30 lb. per acre, which is higher than the loss—21 lb.—from the drainage gauges.

In the drainage gauge the loss besides being smaller is differently distributed: remarkably little occurs during April, May and June (the months of rapid nitrate formation in the field) partly because the drainage water is only small, being 27 per cent. of the rainfall, instead of 50 per cent. the average for the year, and partly because the concentration of nitrate in drainage water is low. This indicates that the amount formed in the gauges is low during these months, thus constituting a marked difference between field soils and the gauges.

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The chief difference between the field soil and the gauge apparently lies in the fact that the field soil, even though unmanured and lying fallow for one year, receives annual additions of easily decomposable organic matter in the form of the weeds and stubble of the preceding years' crop while the soil of the drain gauge does not. There is no more total nitrogen, but a larger quantity of nitrate is in circulation than in the gauges. During a fallow year the nitrogen of the stubble is released as nitrate and becomes liable to loss, but on cropped land the young plant takes it up and reconverts it into complex compounds. The nitrogen content of the unmanured cropped soil is not widely different from that of the gauges, and the extent to which the nitrogen is finally reduced is substantially the same in both cases: at the present time the figures are:

			Percentage of nitrogen in top 9 inches
Drain gauge	...	...	0.099
Broadbalk unmanured plot			0.088

### *The reliability of the results: the chlorine test.*

The determination of the amount of chlorine in the drainage water is of profound importance as it affords by far the best check on the accuracy of the working. At Rothamsted the chlorine is determined in the rain as well as in the drainage water, but the determinations are made at different times and involve different quantities of liquid corresponding to the differences in concentration. If the work is accurate the total amount of chlorine found in the drainage water at the end of 27 years should equal that found in the rainwater for the same period, for, as has often been shown, soils neither absorb nor give up chlorine to water passing through them. Table VI shows how complete is the agreement: during the 27 years the determinations of chlorine in rain water when added together amount to 441.50 lb., while the determinations of chlorine in the drainage water in the three separate gauges are:

20 ins.	40 ins.	60 ins.	Rain water
441.53	455.80	447.53	441.50 lb. per acre

The number of measurements involved is very large—some 18,000 readings having been taken at the gauges and a large number of titrations made in the laboratory: each gauge reading has to be multiplied by the corresponding titration value. Thus errors are multiplied. Yet over 28 years the widest divergence is only 1.3 per cent., and in the case of the 20 in. gauge considerably less. There is no possibility of

straining readings to compel agreement as the figures were not added up regularly during the course of the work, but only at rare intervals. The remarkable agreement shows that an unusually high degree of credibility attaches to Mr Grey's readings at the gauges and to Dr Miller's titration values: we can without fear proceed to add up the figures for nitrate and draw from them such deductions as seem possible.

*The amount of nitrate washed out from the gauges and its relation to external conditions.*

Although the gauges were set up in 1870 systematic analyses were not begun till 1877; there is no means of knowing the loss during this first period. The amounts of nitrate washed out in the different years subsequent to 1877 are given in Table I, and plotted in Fig. 1. They are subject to large fluctuations from year to year, but they show a tendency to fall off as time goes on. The irregularities are considerably smoothed out by taking four year averages: a fall then appears which is fairly steady excepting during one period—1889-1893; during the first four years for which data are available the loss of nitrogen was at the rate of 44.25 lb. per acre per annum from the 60 in. gauge; during the last two years it had fallen to 22.94 lb. The higher figure corresponds fairly closely with the quantity of nitrogen present in a four quarter wheat crop; Lawes was accustomed to use this figure as an illustration of the wastefulness of winter fallows. The results are:

*Nitric Nitrogen in drainage water, lbs. per acre.*

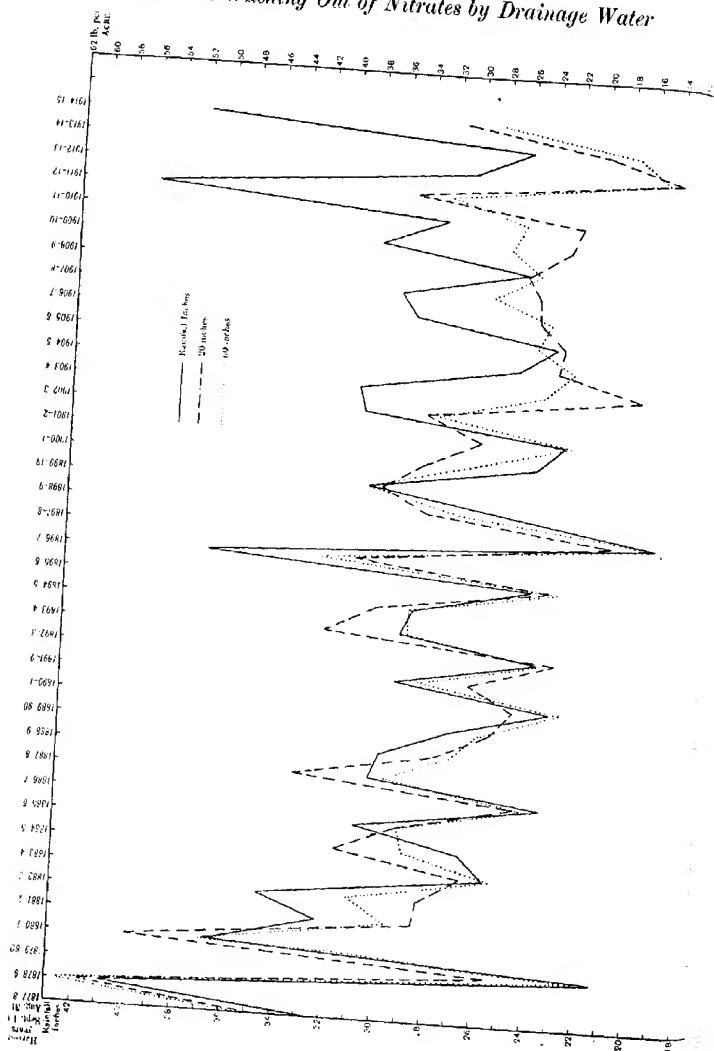
4 year periods	20 in. gauge	60 in. gauge
1877-8 -- 1880-1	47.23	44.25
1881-2 -- 1884-5	33.62	33.56
1885-6 -- 1888-9	33.71	31.38
1889-90 -- 1892-3	26.33	26.90
1893-4 -- 1896-7	34.47	33.27
1897-8 -- 1900-1	30.53	28.22
1901-2 -- 1904-5	25.61	25.32
1905-6 -- 1908-9	24.65	25.66
1909-10 -- 1912-13	23.38	25.33
1913-14 and 1914-15	25.82	22.94

The falling off is very gradual and there is nothing to indicate any difference in the reaction or type of compound decomposed now and in the early days. Only the quantities seem to have become reduced (Fig. 2).

The concentration of nitrate in the drainage water varies from 2 to 20 parts of nitric nitrogen per million of water, the minimum for the year



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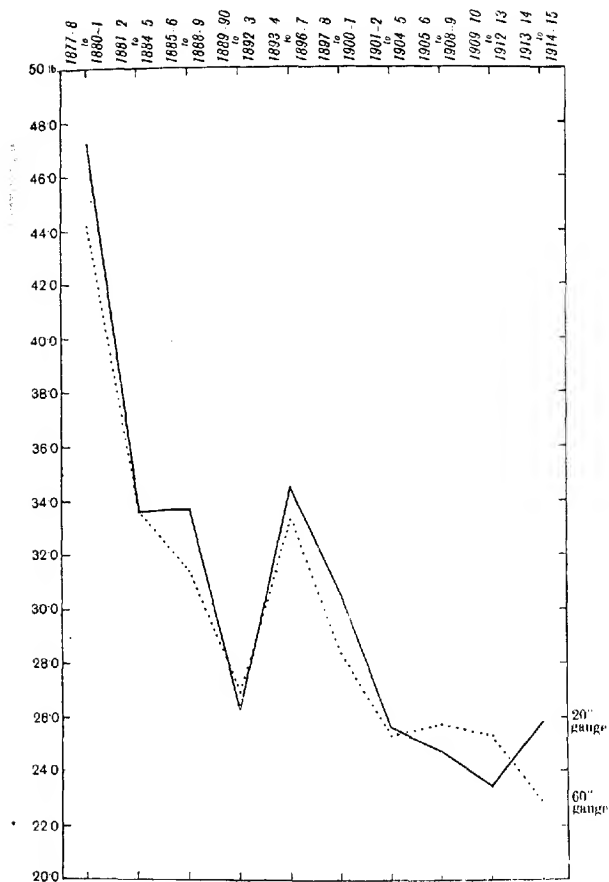


Fig. 2. Nitrogen as nitrate in water draining through 20 (smooth line) and 60 (dotted line) inches of soil: lb. per acre: four year periods.

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commonly occurring in February and March and the maximum in September, October and November. Until the last few years 10 parts per million was a usual quantity but of late 5 parts have been more frequent. Usually there are about 4 parts of chlorine per million. The figure fluctuates only slightly and rarely falls below 3 or rises above 5.

When the data for meteorological conditions—rainfall, sunshine, etc.—are plotted, it is seen that rainfall shows a closer relationship than any other single factor to the nitrate in drainage water. There is some difference in detail in the three gauges. The nitrate figures from the 60" gauge only on two occasions fall out of line with the rainfall, viz. in the seasons 1903-4 and 1906-7. The figures for the 20" gauge fall out four times in the seasons 1882-3, 1903-4, 1907-8, 1909-10. With these exceptions the connection between rainfall and nitrate is so close that a nearly constant figure is obtained when one is divided into the other: the quantity of nitrogen as nitrate washed out for every inch of rain was till 1901 1.0 to 1.2 lb. per acre: since then, however, it has fallen to 0.73 lb. This is shown in Table II.

The quantity of water percolating through the gauge shows nearly as clear a relationship as the rainfall with the amount of nitrate washed out. At first sight it might appear to be the more important factor, but in reality it is not. When the rain starts its downward course in the soil it dissolves some of the nitrate produced in the surface layer: some of it evaporates, the precise amount depending on the temperature of the soil and other factors, but never enough to throw the nitrate out of solution, so that the amount of nitrate finally escaping in the drainage water is influenced less by the proportion evaporated—i.e. the amount that finally percolates—than by the initial amount of rain-water. When the percolation falls below a certain amount, however, it exerts a greater effect than the rainfall.

The relationship between the amounts of rainfall and percolation, and the washing out of nitrates, is shown when the figures are plotted for individual months and not for the whole year. This is done in Fig. 3 (Table II): percolation is seen to be more closely related to washing out in summer than in winter. During the months October to April the amount of nitrate washed out is closely related to the rainfall, more so than to the percolation. During the months April to August, on the other hand, the amount washed out is more closely related to the percolation than the rainfall: the reason for this inversion of relationship is probably that the amount of water percolating is insufficient to wash out the nitrate although the rainfall is rather high.

*The effect of very dry years and very wet years on losses of nitrate from soil.*

Fig. 1 shows that losses of nitrate in any year are nearly — though not quite — proportional to the rainfall. Closer inspection of the data, however, shows that exceptionally wet or exceptionally dry years have after

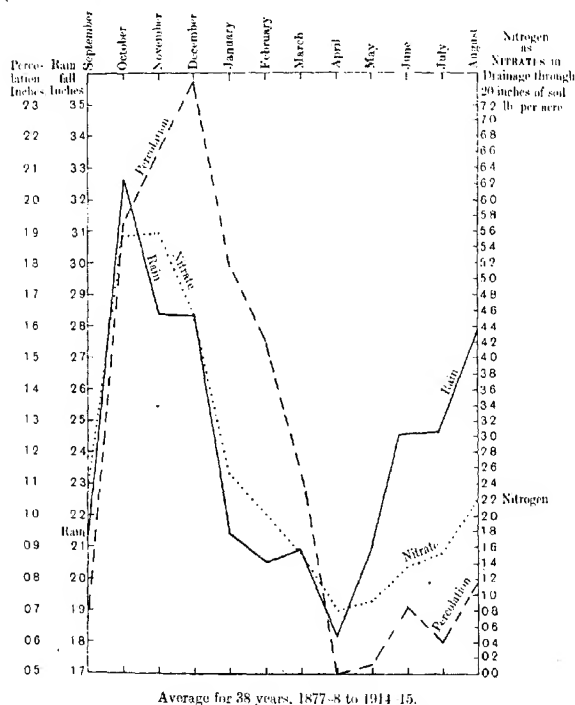


Fig. 3. Nitrogen as nitrate in drainage water, amount of rainfall and of percolation: average for each month, 38 year period.

effects which persist to the following season. During an exceptionally wet year the soil not only loses a large amount of nitrate, but apparently

### 32 *The Washing Out of Nitrates by Drainage Water*

to some extent the power of producing nitrate. This is shown in the following table.

Year	Rainfall inches	Nitrogen in drainage water, lb. per acre		Nitrogen as nitrate washed out per in. of rain			
		20 in. gauge	60 in. gauge	20 in. gauge	60 in. gauge	Average of current 5 years*	
						20 in. gauge	60 in. gauge
1878-9 ...	41.03	59.36	60.94	1.45	1.48	1.34	1.26
Succeeding year ...	21.36	27.03	20.19	1.27	0.95		
1880-1 ...	36.77	57.78	49.95	1.57	1.36	1.25	1.20
1st succeeding year ...	32.31	32.93	35.24	1.02	1.09		
2nd " " ...	34.71	32.67	38.26	0.94	1.10	1.10	1.05
1896-7 ...	37.24	36.62	41.40	0.98	1.11		
Succeeding year ...	19.51	18.20	15.01	0.93	0.77	0.74	0.78
1911-12 ...	39.88	35.14	32.44	0.88	0.81		
Succeeding year ...	27.32	13.83	15.11	0.51	0.55		
Average for whole period	28.94	30.78	30.04	1.06	1.04		

\* Including 2 years before the one mentioned.

In each case after the wet year the soil is left in such state that it does not easily yield up nitrate in the following year: each inch of rain therefore washes out an amount of nitrate which is smaller than in the wet year and below the average for the period.

The period 1881-5 is of interest because three wet years came together at an interval of only one year after the disastrous season 1878-9, and the nitrate lost per inch of rain fell off. Fig. 4 shows that the amount did not completely recover in 1883-4 although this was dry, and it was only in the following year 1884-5, which was dry also, that the washing out became normal.

In some of the very dry years the opposite effect is seen: less nitrate is washed out than is usual during the period, but more is washed out in the following year:

Year	Rainfall inches	Nitrate in drainage water, lb. per acre		Nitrogen as nitrate washed out per in. of rain			
		20 in. gauge	60 in. gauge	20 in. gauge	60 in. gauge	Average of 5 years	
						20 in. gauge	60 in. gauge
1883-4 ...	25.77	29.31	26.89	1.14	1.04	1.15	1.11
Succeeding year ...	26.78	39.55	33.86	1.48	1.26		
1886-7 ...	23.61	25.28	24.98	1.07	1.06	1.13	1.08
Succeeding year ...	30.50	43.10	35.67	1.41	1.17		
1892-3 ...	24.08	22.61	23.72	0.94	0.99	1.11	1.08
Succeeding year ...	29.55	40.94	34.52	1.39	1.17		
1895-6 ...	24.31	23.18	22.78	0.95	0.94	1.10	1.05
Succeeding year ...	37.24	36.62	41.40	0.98	1.11		
1897-8 ...	19.51	18.20	15.01	0.93	0.77	1.17	1.11
Succeeding year ...	24.70	33.23	30.91	1.35	1.25		

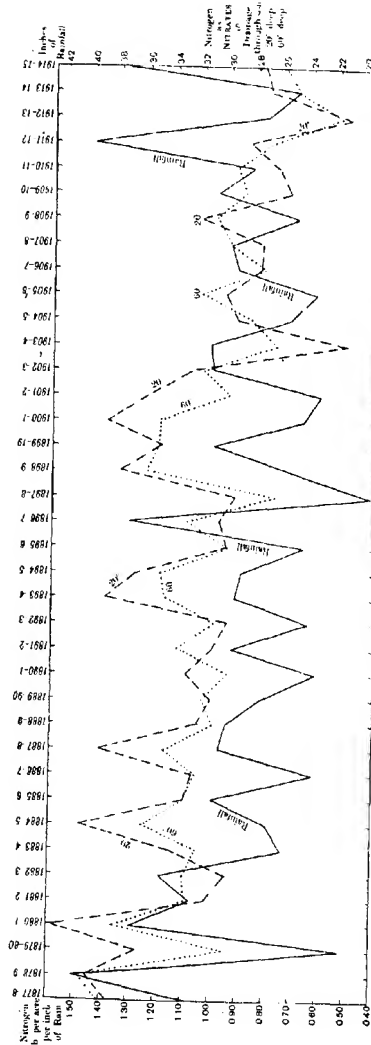


Fig. 4. Yearly amounts of rainfall in inches, and of nitric nitrogen in lb. per acre in the drainage through 20" and 60" of soil for 1 inch of rain.

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But this is not an invariable rule, a certain number of exceptions occur when no more is washed out in the following year :

Year	Rainfall inches	Nitrate in drainage water, lb. per acre		Nitrogen as nitrate washed out per in. of rain		Average of 5 yrs	
		20 in. gauge	60 in. gauge	20 in. gauge	60 in. gauge	20 in. gauge	60 in. gauge
1890-1 ... ..	23.41	25.70	22.04	1.10	[0.94]*	1.09	1.05
Succeeding year ...	29.68	29.39	33.43	0.99	[1.13]		
1901-2 ... ..	23.26	29.12	22.11	1.25	[0.95]*	1.03	0.97
Succeeding year ...	31.25	33.70	32.73	1.08	[1.03]		
1905-6 ... ..	23.75	22.90	24.94	0.96	1.05	0.92	0.94
Succeeding year ...	29.35	21.74	23.96	0.84	0.82		

\* These conform to the general rule.

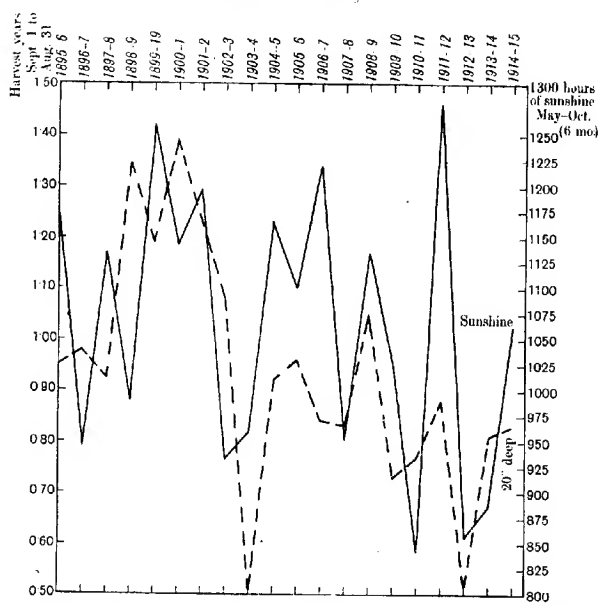


Fig. 5a. Yearly amounts of nitrogen as nitrate in the drainage through 20 inches of soil for 1 inch of rain in pounds per acre (dotted line); also hours of sunshine (smooth line) for 6 months (May–October) of first named year.

*The effect of temperature on the loss of nitrate from the soil.*

The effect of temperature is so much masked by the rainfall that it is only seen when the amounts of nitrate washed out per inch of rain are plotted on rather a wide scale, and compared with the sunshine curves for the preceding summer months. Soil temperature would of course be better, but unfortunately the data are not available; sunshine, however, generally fluctuates in much the same way as soil temperature. Even then a strict comparison is rendered difficult by the persistent effect of very wet or very dry years already mentioned. The data show that a relationship exists between summer sunshine and the following

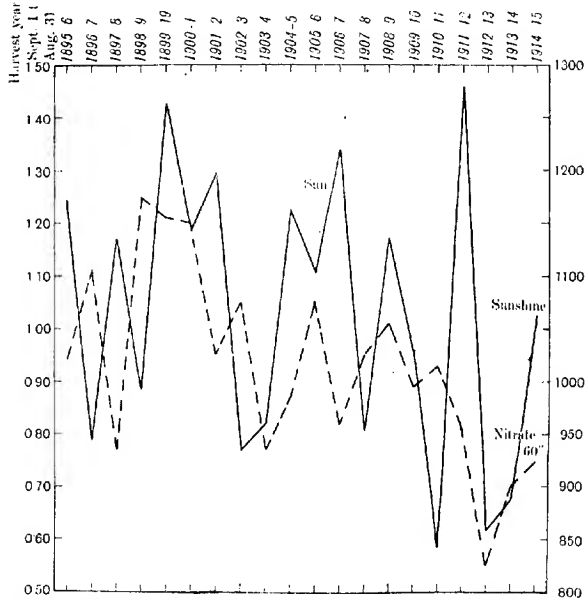


Fig. 5b. Yearly amounts of nitrogen as nitrate in the drainage through 60 inches of soil for 1 inch of rain in pounds per acre (dotted line); also hours of sunshine (smooth line) for six months (May to October) of first named year.

winter losses of nitrate, the loss tending to be higher after a hot summer than after a cold one (Fig. 5). Again, however, the effect is not simple as a hot summer is usually also a dry one.



### 36 *The Washing Out of Nitrates by Drainage Water*

*The total amount of nitrogen removed from the soil in the gauges.*

The total amount of nitrogen in the drainage water from the gauges during the whole period of 38 years—1877-1915—in which continuous determinations have been made is as follows:

20 in.	40 in.	60 in. gauge
1170	1007	1141 lb. per acre

The 20 and 60 inch gauges have on the whole given very similar results, but the 40 inch gauge has always shown certain differences which could never be explained. It is not easy to assign any specific cause: one possible disturbing factor is that a number of solitary bees have chosen to reside in the soil of the gauges, and any carbohydrate attached to the pollen they brought in would reduce the amount of nitrate in the drainage water. The marked depressing effect of soluble carbohydrates was demonstrated in the years 1906, 1908 and 1909, when additions of starch or sugar were made to the 40 inch gauge, but not to the others: the experiment was designed for another purpose, but fortunately throws light on this problem.

Date	Substance added to 40 in. gauge	Nitrate in 60 in. gauge (no carbohydrate added)	
		Nitrate in 40 in. gauge Sept. 1906 Aug. 1912	Sept. 1906-Aug. 1912
Apr. 4, 1906	1 lb. starch and 80 gm. calcium phosphate	29.76	23.96
	1907 Nothing	19.35	28.68
Jan. 27, 1908	4 lb. sugar	7.97	25.07
" 1909	" icing sugar	10.58	27.49
	1910 Nothing	17.95	26.31
	1911 "	25.25	32.44
	1912 "	12.52	15.11

Seeing that 8 lb. of sugar has caused a reduction of 55 lb. of nitrate it is obvious that no large amount of carbohydrate would be needed annually to account for the difference of 140 to 160 lb. over the whole period. It is impossible now to ascertain how large a part has been played by these bees, and no estimate of their number has been made. The observer, E. Grey, has seen them for a number of years, but more on the 40 inch gauge than on the others.

The close similarity between the 1170 lb. of nitrate washed out from the 20 inch gauge and the 1141 lb. washed out from the 60 inch gauge shows that the nitrate comes only from the surface layers and not at all from the lower depths: there is no evidence that the lower 40 inches has contributed anything at all, and if this is the case there is no reason to go below the top 9 inches for the source of the nitrate. Analysis of the

soil at the beginning and end of the experiment shows how much nitrogen has been lost from the top 9 inches of soil; the amounts are:

	20 in. gauge	60 in. gauge
Present in 1870	3500	3500 lb. per acre in top 9 inches
" 1917	2376	2328 " "
Loss from top 9 ins.	1124	1172 lb. per acre

(See Table IV, p. 31.)

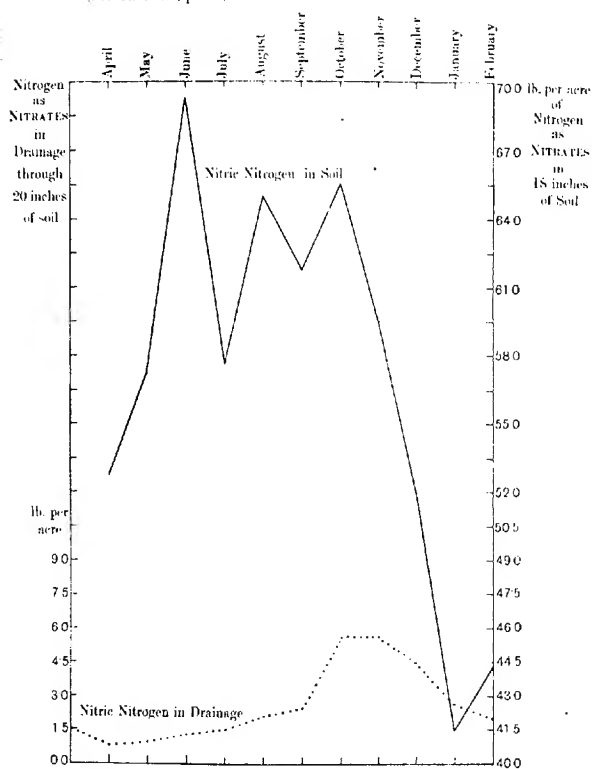


Fig. 6. Nitric nitrogen in soil (Broadbalk unmanured and uncropped) and in drainage water from unmanured and uncropped gauge.

### 38 *The Washing Out of Nitrates by Drainage Water*

The figures 1124 and 1172 lb. per acre of nitrogen lost from the gauges are remarkably similar to the 1170 and 1141 lb. of nitric nitrogen found in the drainage water, but the similarity is only accidental: the periods are not co-terminous and a complication is introduced by the nitrogen compounds in the rain. It is necessary to add to the drainage water figures the nitrate washed out in the first 7 years and the last 15 months (the analyses being discontinued in Dec. 1915 while the soil samples were not taken till April 1917), and to deduct from them the amount brought down in the rain during the 47 years that elapsed between the first and the last sampling. The amount contained in the rain is known to be 5 lb. per annum or 235 lb. over the whole period. If all this came from outside sources the case would present no difficulties. But evidence has been adduced<sup>1</sup> to show that some of the nitrogen compounds in the rain have come from the soil, so that an unknown part of this 235 lb. is not new nitrogen but simply soil nitrogen which has come into the drainage water by a more circuitous route than the rest.

It is impossible now to arrive at any exact estimate of the nitrogen washed out in the first 7 years. Dr Miller put it at:

20 in. gauge	40 in. gauge	60 in. gauge
231	204	223 lb. per acre

We are inclined to put the figure higher. During the 7 years 212 inches of rain fell; and throughout the subsequent 4 year period—1877–1881—each inch of rain washed out 1.33 lb. of nitric nitrogen from the 20 inch gauge and 1.25 from the 60 inch gauge. The rates during the first 7 years would almost certainly be higher. The total nitrate washed out would therefore be not less than 283 lb. and 265 lb. respectively, and in all probability would be more. In the 15 months from January 1916 to April 1917 a further 29 lb. would be washed out. Thus the total nitric nitrogen in the drainage water for the whole period of 47 years appears to be:

	20 in. gauge	60 in. gauge
Estimated 1870-77	283	265 lb. per acre
Found 1877-1915	1170	1141 " "
Estimated 1915-17	29	29 " "
Total	1482	1435 " "

The nitrogen supplied by the soil and the rain has been:

	20 in. gauge	60 in. gauge
Removed from the top 9 ins. of soil, 1870-1917	1124	1172 lb. per acre
Brought in by rain	235	235 " "
Total	1359	1407 " "
Found in drainage water	1482	1435 " "
Balance, being excess found	123	28 " "

<sup>1</sup> *This Journal*, 1910, 9.

The nitrate in the drainage water accounts for practically all the nitrogen lost from the soil: the uncertainty attaching to the estimated figures and to the actual amount of new nitrogen in the rainfall deprives the balance sheet of precision, but there is no room for much fixation or loss of gaseous nitrogen. The chief, if not the sole action, in this soil where there is no manure, crop residues or fresh supply of organic matter, is the production of nitrate. It is in these circumstances that the nitrogen cycle is seen at its simplest. We know from other Rothamsted experiments that the cycle becomes more complex when organic matter is added to the soil: both fixation and loss of nitrogen being then liable to occur.

Table I.

*Yearly amounts of Nitrogen as Nitrates in the Drainage water through 20, 40 and 60 inches of Soil.*

(The earlier results are recorded in this *Journal*, 1906, 1, 388.)

	Rainfall (1/4 acre gauge)	Drainage water			Nitrogen as nitrate, lb. per acre		
		Soil 20 in. deep	Soil 40 in. deep	Soil 60 in. deep	Soil 20 in. deep	Soil 40 in. deep	Soil 60 in. deep
	inches	inches	inches	inches	lb.	lb.	lb.
Sept. 1 to Aug. 31							
1905-6	23.75	11.54	12.21	11.97	22.90	20.68	24.94
1906-7	29.35	12.22	12.72	12.34	24.74	20.76	23.96
1907-8	30.11	15.43	16.37	15.19	24.86	19.35	28.68
1908-9	24.92	11.49	11.63	11.09	26.00	7.97	25.07
1909-10	30.92	15.66	15.68	15.43	22.70	10.58	27.47
1910-11	28.35	16.72	16.66	17.04	21.83	17.95	26.31
1911-12	39.88	25.71	25.35	24.67	35.14	25.25	32.44
1912-13	27.32	15.28	15.63	15.57	13.83	12.52	15.11
1913-14	25.02	13.04	12.86	12.51	20.13	24.31	17.48
1914-15	37.87	24.80	24.80	24.19	31.52	30.92	28.40
Average for:							
last 10 years	29.75	16.19	16.39	16.00	24.37	19.63	24.99
whole period	28.94	14.74	15.42	14.78	30.78	26.49	30.04

## 40 *The Washing Out of Nitrates by Drainage Water*

Table II.

*Monthly amounts of Nitrogen as Nitrates in the Drainage water through  
20, 40 and 60 inches of Soil. Average 38 years.*

(For earlier results see this *Journal*, 1906, 1, 389.)

1877-8 to 1914-15	Rainfall (1/10 acre gauge) inches	Drainage water			Nitrogen as nitrates					
		20 in. gauge inches	40 in. gauge inches	60 in. gauge inches	Per million			Per acre		
					20 in. gauge	40 in. gauge	60 in. gauge	20 in. gauge lb.	40 in. gauge lb.	60 in. gauge lb.
Sept. ...	2.44	0.71	0.69	0.65	14.94	10.82	11.55	2.40	1.69	1.50
Oct. ...	3.26	1.92	1.89	1.78	12.72	9.40	11.19	5.53	4.02	4.51
Nov. ...	2.83	2.17	2.23	2.13	11.32	9.29	10.12	5.56	4.69	4.88
Dec. ...	2.82	2.37	2.46	2.39	8.39	7.60	8.56	4.50	4.23	4.65
Jan. ...	2.14	1.78	1.95	1.91	6.28	6.32	7.56	2.53	2.79	3.27
Feb. ...	2.05	1.55	1.67	1.61	5.73	5.79	7.24	2.01	2.19	2.66
March ...	2.09	1.13	1.27	1.21	5.98	5.64	7.67	1.53	1.62	2.10
April ...	1.82	0.49	0.56	0.54	6.94	6.07	8.26	0.77	0.77	1.00
May ...	2.10	0.53	0.59	0.55	7.59	6.29	8.03	0.91	0.84	1.00
June ...	2.45	0.71	0.73	0.71	8.34	6.54	8.28	1.34	1.08	1.30
July ...	2.46	0.60	0.61	0.58	11.19	8.11	9.75	1.52	1.12	1.20
August ...	2.78	0.78	0.77	0.72	12.35	8.32	10.37	2.18	1.45	1.60
Oct. Mar.	15.49	10.92	11.47	11.03	8.76	7.53	8.82	21.66	19.54	22.40
Apr.-Sept.	13.75	3.82	3.95	3.75	10.55	7.77	9.44	9.12	6.95	8.06
Year ...	28.94	14.74	15.42	14.78	9.23	7.50	8.98	30.78	26.49	30.06

Table III.

*Amounts of Nitrogen as Nitrates in the Drainage through 20 and 60 inches  
of Soil, from 1877-8 to 1914-15 in 4-year periods.*

4-year periods	Rainfall inches	Drainage through 20 in. gauge	Drainage through 60 in. gauge	Nitrogen as nitrate, lb. per acre		Nitrogen washed out, per inch of rain, lb. per acre	
				20 in. gauge	60 in. gauge	20 in. soil	60 in. soil
1877-8 —1880-1	35.46	17.11	16.75	47.23	44.25	1.33	1.25
1881-2 —1884-5	29.89	15.83	14.81	33.62	33.56	1.12	1.12
1885-6 —1888-9	28.81	14.15	14.32	33.71	31.38	1.17	1.09
1889-90 —1892-3	26.15	12.80	12.76	26.33	26.90	1.01	1.03
1893-4 —1896-7	30.03	15.15	15.88	34.47	33.27	1.15	1.11
1897-8 —1900-1	24.88	11.30	11.97	30.53	28.22	1.23	1.13
1901-2 —1904-5	27.83	13.22	13.92	25.61	25.32	0.92	0.91
1905-6 —1908-9	27.03	12.67	12.65	24.65	25.66	0.91	0.95
1909-10 —1912-13	31.62	18.34	18.18	23.38	25.33	0.74	0.80
1913-14 —1914-15	31.45	18.92	18.35	25.82	22.94	0.82	0.73

Table IV.

*Nitrogen content of soil in drain gauges.*

1. At beginning. Samples taken June 27th-28th, 1870; using iron frame  $6 \times 6 \times 9$  inches, "near new rain gauge," but not from the drain gauges themselves:

	Bare ground		Barley ground	
	per cent.	lb. per acre	per cent.	lb. per acre
1st 9 ins.	0.146	3500	0.139	3260
2nd 9 ins.	0.078	2080	0.074	1850
3rd 9 ins.	0.076	1900	0.060	1640

(Conversion factors (weights of dry soil, lb. per acre)

	Bare ground	Barley ground
1st 9 ins.	2,391,895	2,341,275
2nd 9 ins.	2,667,067	2,495,002
3rd 9 ins.	2,511,917	2,738,900

(weights deduced from actual weight of sample)

Neither sample was taken from the gauge itself, and the spots from which they were drawn cannot now be located. But Lawes and Gilbert considered the "Bare ground" sample more closely representative of the gauge than the "Barley ground," and these figures have therefore always been adopted.

2. At end. Samples taken April 17th, 1917, from gauges themselves, 2 inch cylindrical borer used. One sample only taken.

	Per cent. of nitrogen			Weight of nitrogen, lb. per acre		
	20 inch	40 inch	60 inch	20 inch	40 inch	60 inch
1st 9 ins.	0.099	0.096	0.097	2376	2299	2328
2nd 9 ins.	0.074	0.066	0.057	1954	1794	1520

(Conversion factors (weights of dry soil, lb. per acre)

1st 9 ins.	2,400,000
2nd 9 ins.	2,650,000
3rd 9 ins.	2,700,000

Averages for Rothamsted soils generally.

Samples taken from land near gauge.

	Mangold plots		Grassland
	1 C.	4 C.	
1st 9 ins.	0.202	0.109	0.227
2nd 9 ins.	0.059	0.055	0.079
3rd 9 ins.	0.046	0.043	0.059

Table V.  
*Annual Amounts of Chlorine in the Rain and the Drainage through 20,  
40 and 60 inches of Soil. Gain or Loss of Chlorine in the Soil.*

Harvest years Sept. to August	Rainfall			Drainage			In drainage			Gain on Loess in soil			Soil 60 ins. deep			Soil 40 ins. deep			Soil 20 ins. deep		
	inches	Soil	Soil	Soil 60 ins. deep	In rain lb.	Soil 20 ins. deep	Soil 40 ins. deep	Soil 60 ins. deep	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	lb.	
		20 ins. deep	40 ins. deep																		60 ins. deep
1905-6	29.75	11.54	12.21	11.97	14.96	14.74	15.31	15.12	-0.22	-0.35	-0.16	-0.35	-0.16	-0.35	-0.16	-0.35	-0.16	-0.35	-0.16	-0.35	
1906-7	29.35	12.22	12.97	12.34	16.95	12.65	14.08	13.85	+3.40	+2.87	+3.10	+3.40	+2.87	+3.10	+3.40	+2.87	+3.10	+3.40	+2.87	+3.10	
1907-8	30.11	15.43	16.37	15.19	19.84	22.84	21.09	21.06	-3.60	-4.00	-1.25	-1.25	-1.22	-1.22	-1.25	-1.22	-1.22	-1.25	-1.22	-1.22	
1908-9	24.92	11.49	11.93	11.09	13.61	14.76	13.94	15.05	+1.15	+0.33	+1.44	+1.15	+0.33	+1.44	+1.15	+0.33	+1.44	+1.15	+0.33	+1.44	
1909-10	30.92	15.66	15.98	15.43	19.33	15.54	16.89	18.68	+3.79	+3.44	+0.65	+3.79	+3.44	+0.65	+3.79	+3.44	+0.65	+3.79	+3.44	+0.65	
1910-11	28.35	16.72	16.60	17.04	21.76	19.55	17.64	20.23	+2.21	+4.12	+1.53	+2.21	+4.12	+1.53	+2.21	+4.12	+1.53	+2.21	+4.12	+1.53	
1911-12	30.88	25.71	25.35	24.67	19.23	28.44	27.67	28.70	-0.21	-8.74	-9.47	-0.21	-8.74	-9.47	-0.21	-8.74	-9.47	-0.21	-8.74	-9.47	
1912-13	27.32	15.28	15.63	15.57	17.02	13.61	13.84	14.81	+4.01	+3.78	+3.81	+4.01	+3.78	+3.81	+4.01	+3.78	+3.81	+4.01	+3.78	+3.81	
1913-14	25.02	14.04	12.86	12.51	14.15	16.25	16.22	15.71	-2.10	-2.07	-1.56	-2.10	-2.07	-1.56	-2.10	-2.07	-1.56	-2.10	-2.07	-1.56	
1914-15	37.87	24.80	24.80	24.19	21.05	27.19	26.73	28.23	+5.24	-4.78	-6.28	+5.24	-4.78	-6.28	+5.24	-4.78	-6.28	+5.24	-4.78	-6.28	

Table VI.

*Chlorine in Rainwater, and Drainage for 7 periods of 4 years 1888-9 to 1915-16.*

		Chlorine per acre in lb. per annum				
		In drainage				
Sept. 1—Aug. 31		Rainfall in ins.	In rainwater	Soil 20 ins.	Soil 40 ins.	Soil 60 ins.
1888-9	}	27.65	12.25	12.24	13.27	12.45
1891-2						
1892-3	}	27.95	14.35	14.15	15.19	14.24
1895-6						
1896-7	}	28.12	17.90	16.26	17.41	16.07
1899-1900						
1900-1	}	27.58	17.23	17.67	18.65	17.79
1903-4						
1904-5	}	27.14	16.75	16.23	16.18	16.00
1907-8						
1908-9	}	31.03	18.48	19.57	18.86	20.67
1911-12						
*1912-13	}	30.07	17.91	19.02	18.93	19.58
1914-15						
Totals for 27 years		763.21	441.50	441.53	455.80	447.58
Average per annum		28.27	16.35	16.35	16.88	16.58

\* 3 years only.

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# THE RELATIONS EXISTING BETWEEN THE SOIL AND ITS WATER CONTENT.

## A RÉSUMÉ OF THE SUBJECT.

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### (A) INTRODUCTION.

IN any systematic account of the work done on the moisture in soil and its behaviour under varying conditions, it is necessary to keep constantly in mind that the underlying hypotheses have been profoundly modified in recent years. When physical methods were first applied to the examination of soils, the results were interpreted on the obvious hypothesis that the soil could be regarded as composed of mineral particles of varying shapes and sizes, over the surfaces of which the water was distributed in a thin film. The movements of the film water and its average thickness at any time, under the varying meteorological and soil influences, could be predicted more or less completely from known physical principles such as surface tension, etc. Similarly, the concentration of the plant nutrients in the soil moisture was considered mainly as a matter of solubility in, and diffusion within, this moisture. The foundation of the subject of soil physics was laid upon these lines in the early 19th century by Davy<sup>1</sup> and Schübler<sup>2</sup>.

From 1850 onwards very few physical investigations were made on soil, and the subject became overshadowed by agricultural chemistry. Subsequently interest in soil physics revived and considerable developments were made in America and Germany. Of recent years further impetus has been given to the science by the recognition of the adsorptive and colloidal phenomena shown by soils. These effects have profoundly modified the older views on the relations existing between soil and its water content, and have revealed a much more intimate connection. It is no longer sufficient to imagine a mineral-grain framework covered with a film of water. Colloidal material exists in the soil, derived both

<sup>1</sup> Davy, H. *Elements of Agricultural Chemistry*, 1st ed. (1813). London.

<sup>2</sup> Schübler, G. *Gründsatze der Agrikultur-Chemie*, (1830). Leipzig.

from the humus and the clay fraction, and exerts in most cases a controlling influence on the water relationships. The constitution of this colloidal complex is by no means fully worked out, but a satisfactory provisional hypothesis for physical investigations is to assume that it coats more or less completely the soil-grains, especially those of smaller size.

The relations existing between soil and its moisture content are subject to so many variable factors that separation for purposes of discussion is only possible in a very general way. This difficulty did not exist to so great an extent with the original hypothesis, because the soil water could be conveniently classified as (1) hygroscopic moisture, (2) capillary water, (3) gravitation water<sup>1</sup>. Gravitation water is defined as the water in excess of the amount the soil can retain under existing conditions and which can therefore drain away. The capillary water is that part retained in the capillary spaces under these conditions, and is capable of movement through capillary action. The hygroscopic water is the film on the surface of the grains, and is not capable of movement under gravitational or capillary forces. With this classification it was comparatively simple to treat any one aspect of soil moisture behaviour, such, for instance, as evaporation or percolation. But when similar treatment is attempted on the colloidal hypothesis, the more intimate relations postulated between the soil material and the water—relations which vary in a continuous manner over a wide range of moisture content—render the above divisions too empirical for a theoretical basis. The classification is undoubtedly convenient, especially in field studies, but its somewhat arbitrary nature should be kept in view.

These considerations are reflected both in the arrangement of the present paper and in the choice of material for discussion. A full treatment is given of the comparatively few recent papers in which the colloidal hypothesis is accepted, while the greater amount of work interpreted on the older theory is represented by typical papers; results which have a bearing upon the colloidal hypothesis, however, are especially noted. The section dealing with the hygroscopicity of soils is fully treated, because this phase of the subject is likely to help considerably in extending our knowledge of the colloidal nature of soil.

#### (B) SOIL MOISTURE IN GENERAL

The amount of soil moisture may vary between wide limits for any one type of soil, ranging from a water-logged condition, when the pore space between the particles is practically filled with water, to almost

<sup>1</sup> Briggs, L. J. *U.S. Bureau of Soils, Bull.* 10 (1897).

complete dryness. A good proportion of the earlier work on soil physics was devoted to experiments on the amount of water held in the soil under varying conditions, and a broad series of divisions was worked out.

(a) *The maximum water capacity and pore space.*

King<sup>1</sup> did a considerable amount of work on the maximum water capacity, which is defined as the amount of water necessary completely to fill the interspaces between the particles. It is obvious that the mode of packing of the soil particles will directly affect this value. King therefore employed soils in their natural condition of consolidation, obtained by driving metal cylinders into the soil. When the desired depth was reached the surrounding soil was removed, and the cylinder, full of soil, taken for experiment. The results are given in Table I, and show the progressive diminution in the maximum water capacity, with increasing

Table I.

*Maximum water capacity of different depths of soils (King).*

Depth of sample inches	Weight when full of water lb.	Weight dry lb.	Weight of water lb.	Water expressed in inches	Per cent. of water
1-12	21.33	15.09	6.24	5.88	41.3
12-24	24.27	18.94	5.33	5.03	28.1
24-36	24.27	18.89	5.38	5.07	28.4
36-48	24.89	19.94	4.95	4.67	24.8
48-60	26.91	22.92	3.99	3.76	17.4

depth of soil. The water necessary for saturation was found to be greater in amount than the maximum values observed in the field when the soils were water-logged, owing to the more complete displacement of air in the laboratory experiments. The main value of experiments of this type lies in the information afforded on the pore space in soils. This is essentially a function of the size and mode of packing of the particles, but is also affected by the proportion of organic and colloidal matter present. These materials, besides having an important bearing on the formation of compound particles, and hence directly on the pore space—a phase discussed in more detail in the section below dealing with the hygroscopic coefficient—also imbibe large quantities of water and swell considerably, thus increasing the effective volume of a given weight of soil, and allowing it to take up more water than it would otherwise do.

(b) *The permeability of soil.*

The pore space in soils can also be studied by permeability methods. The permeability of a soil may be measured by that volume of liquid

<sup>1</sup> *Wisconsin Agric. Expt. Station 6th Rept.* (1889), p. 189.

which will pass per second through a soil column of 1 c.c. cross-sectional area, and 1 cm. in length under 1 cm. head of pressure. The liquid usually employed is water, but the permeability to gases can also be measured, and is defined in a similar manner.

By far the most exhaustive study on these lines has been done by King<sup>1</sup>, who examined the permeability both for air and water of many porous rocks, and a large number of porous media. Various devices were used for the latter in an attempt to bridge the gulf between a capillary tube of uniform bore, in which the flow follows the well-known Poiseuille-Meyer Law, and a mass of particles, which gives in effect a number of irregular channels between the grains. These devices consisted of bundles of capillary tubes, bundles of knitting needles, brass tubes containing discs of wire-gauze, closely packed but haphazardly orientated, tubes of quartz sand of various grain size, and so on. King finds almost invariably a departure from the proportionality between flow and pressure which would be expected from Poiseuille's law, the flow increasing faster than the pressure. The reason for this is very difficult to understand. Röntgen<sup>2</sup>, Warburg and Sachs<sup>3</sup>, and R. Cohen<sup>4</sup>, have all shown that the viscosity of water diminishes slightly with increasing pressure, but this diminution is not nearly sufficient to account for the observed increase of flow with pressure. The possibility that entrapped air in the materials was gradually washed out as the pressure head was increased is largely negated by the careful technique used. A satisfactory explanation is, as yet, wanting. King's attempt to show that his observed increases are paralleled by similar results obtained in the classical experiments of Poiseuille and Meyer, on which the laws of capillary flow were based, is not completely convincing.

C. S. Slichter, in an appendix to King's work, has examined the mathematical conditions involved in the flow through porous media on the assumption that the particles are spheres of one size. Generally he confirms the experimental results, and is able to show that slight increases in the porosity of a soil due to the more open packing of the grains have an enormous influence on the flow of water or vapour through the soil. If two samples of the same sand are packed so that the pore space is 26 per cent. in one case and 47 per cent. in the other, the flow through the former is only one-seventh of that through the latter,

<sup>1</sup> King and Slichter. "Principles and conditions of the movements of ground water." 1916 *Annual Report*, 1899 (Pt II), (U.S. Geol. Survey).

<sup>2</sup> *Wied. Ann.*, 22 (1884), p. 510.

<sup>3</sup> *Wied. Ann.*, 22 (1884), p. 513.

<sup>4</sup> *Wied. Ann.*, 45 (1892), p. 666.

while if the pore spaces are 30 per cent. and 40 per cent., the flow through the latter is 2.6 times that through the former.

Green and Ampt<sup>1</sup>, in some ingenious experiments, have examined some of Slichter's results, both for "ideal" soils<sup>2</sup> and quartz sands. They obtain the paradoxical result that Slichter's permeability formula closely expresses the results for the irregular grains of quartz sand, but not for the spherical particles composing the "ideal" soil. They believe that the explanation of this is to be found in Slichter's method of treating each soil capillary as if it were a double triangular shaped pore with a partition down its centre, instead of an *undivided* approximately rhomboidal pore at its narrowest part. Reference to Fig. 1 taken from Green

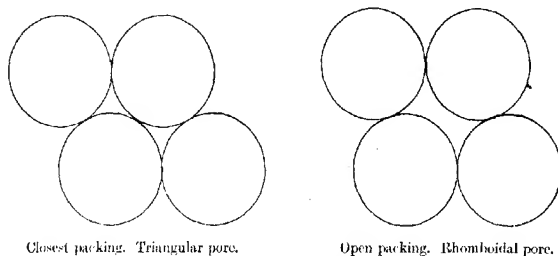


Fig. 1. Arrangements of spheres in an ideal soil (Green and Ampt).

and Ampt's paper, will make this clear. It is not until the closest packing of the spheres is attained that the pore is divided into two. Extrapolation of the experimental results to the minimum pore space, which is reached when the spheres are packed as closely as possible, gives a value approximating to Slichter's theoretical value. For all the other systems of packing the rhomboidal pore will have a considerably greater permeability than Slichter's method of analysis would imply. On the other hand the angular shapes of the quartz sand have the effect of dividing the pore into triangular passages, and hence the agreement of experiment with theory is better in this case.

<sup>1</sup> *Journ. Agric. Science*, 5 (1912-13), p. 1.

<sup>2</sup> Green and Ampt state that the so-called "glistening dew" of the picture post-card artist is composed of almost perfectly spherical grains or beads of glass of diameter .25 mm. upwards, and is thus an invaluable material for experimental tests of theoretical deductions, such as those of Slichter.

(c) *Capillary effects and the "water retaining capacity."*

In earlier experiments on the same lines as those quoted in the preceding sub-section, Green and Ampt<sup>1</sup> found that the permeability of an actual soil when measured with water was less than with air as the experimental fluid, and that the ratio of these two values varied with the amount of colloidal matter present.

As noted above, the imbibition of water by the colloidal material means that a soil, draining under the influence of gravity, will hold up more water than it would otherwise do, and, in addition, the diminution in the diameter of the capillary pores as a result of the swelling of the gel-material will tend to increase this amount still further owing to the production of more effective interstices between the soil particles. It would therefore be expected that the permeability of the soil to water would decrease with increase in colloidal and organic matter.

The following values taken from Green and Ampt's paper illustrate this (Table II).

The actual permeability ( $P$ ) of a soil can be shown to vary inversely as the viscosity ( $\eta$ ) of the fluid used in the experiment. Hence if two different fluids are used, say air ( $a$ ) and water ( $w$ ), the value of the ratio  $\frac{\eta_a P_a}{\eta_w P_w}$  should be unity, provided that the permeability is unaffected by any action of the fluid on the soil.

Table II.

Values of Ratio  $\frac{\eta_a P_a}{\eta_w P_w}$  for three soils (Green and Ampt).

Canterbury Sand	... 2.0, 2.0
University Loam	... 3.5, 3.6, 3.1, 4.1, 6.0
Wormee Clay	... 11.2, 12.3, 14.2

It will be seen that the values increase rapidly with increasing percentage of clay. This is due to the imbibition of the water by the colloidal portion of the clay, and the resulting constriction of the capillary pores. Low values are thus obtained for  $P_w$ , and are reflected in the high values of the ratio  $\frac{\eta_a P_a}{\eta_w P_w}$ .

Crump<sup>2</sup> shows that the organic material has considerable influence on the total amount of water held. Working with extreme types of organic soils, such as moorlands and peats, he finds that a definite relationship

<sup>1</sup> *Journ. Agric. Science*, **4** (1911-12), p. 1.

<sup>2</sup> *New Phytologist*, **12** (1913), p. 125.

olds for any one type of moor or peat soil, between the amount of organic and colloidal material—collectively referred to as the humus content by Crump—and the water content. The latter was obtained by measuring the loss of water occurring when the peat was thoroughly air dried at about 15° C., and the former was determined by the difference in weight when the peat, previously heated at 100° C. to drive off hygroscopic moisture<sup>1</sup>, was ignited to a dull red heat. Over the whole of the experiments it was found that the ratio  $\left(\frac{\text{water content}}{\text{humus content}}\right)$  was very nearly a constant for any one type of soil. This constancy persisted when varying depths of the soil were separately examined, in spite of the considerable difference in actual moisture content. Crump proposes to call this ratio the “coefficient of humidity” and considers it is the best way of expressing the water content. The subjoined table is typical (Table III).

Table III.

*Values of the coefficient of humidity (Crump).*

Material		Water at 15° C.	Humus	Water Humus
(i)	Humus at 1–2½ ins. ...	170.0 %	55.5 %	3.06 %
(ii)	Sandy soil below (i) ...	30.4	10.4	2.92
(i)	Black soil at ½ 1½ ins. ...	67.4	33.4	2.01
(ii)	Same at 1½–2½ ins. ...	40.3	18.6	2.16

It will be seen that a close relationship holds in these extreme types of soil between the amount of humus and the moisture in excess of the hygroscopic moisture<sup>2</sup>. Data are as yet lacking for similar determinations on ordinary soils, but some preliminary work of Crump in the paper mentioned seems to indicate that similar relationships will hold for the colloidal clay content in these soils as for the humus content in the peats.

Recent work of Alway and Neller<sup>3</sup> on the influence of organic matter upon the water-holding-capacity of arable soils indicates that slight differences in moisture content between adjacent plots can be accounted for on the assumption that the organic matter has the same water-holding capacity as some of the most adsorbent peats. These retain, even when well drained, 300 to 400 parts of water to 100 parts of dry

<sup>1</sup> I.e. the moisture remaining in the 15° C. air-dried sample.

<sup>2</sup> The hygroscopic moisture is the amount of water held by an air dried soil and should not be confused with the hygroscopic coefficient, which is the amount of water taken up by a dry soil when exposed to a saturated atmosphere of water vapour. There is, of course, a general parallelism between the two.

<sup>3</sup> *Journ. Agric. Res.*, **16** (1919), p. 263.

peat. Alway and Neller found that a difference in manurial treatment on two adjacent plots had resulted in a difference of 1.37 per cent. in the organic matter, which gives a calculated difference in the water-holding capacity of about 5 per cent. The observed value was approximately equal to this. It should be noted that even if the whole of the organic matter present has the high water-holding capacity of 400 per cent., this will on the average account for only about 50 per cent. of the moisture content. Thus the plot containing 3.39 per cent. of organic matter varied in moisture content from 19.0 per cent. to 28.9 per cent., and the plot with 4.76 per cent. organic matter from 20.1 per cent. to 33.0 per cent. Other factors such as the colloidal property of the clay must therefore be included.

It is clear from the experiments of Crump, Green and Ampt, that the capillary effects in soils are very dependent upon the nature of the surface of the pore spaces. If these surfaces are mainly gel-like in character there is every reason to believe that the water relationships will be profoundly influenced.

The foregoing considerations indicate the main factors concerned in the "water-retaining-capacity" of a soil. This is defined as the amount of water a previously saturated soil retains when allowed to drain thoroughly into the subsoil under the action of capillary forces and gravity, while protected from evaporation. It is obviously of practical importance, because it gives some measure of the actual amount of water retained by soils under natural conditions, and closely corresponds to the sum of capillary and hygroscopic water in Briggs' classification of soil moisture<sup>1</sup>. A large number of determinations have been made on this quantity, both under laboratory and field conditions, but the modes of procedure vary very considerably and there is, at present, no widely adopted standard method. It depends on the soil structure and texture, the water-retaining-capacity being greater the larger the number of interstices in a given volume of soil, and also, as mentioned above, on the nature of the soil particle surface, the water-retaining capacity increasing with the percentage of organic or colloidal water. Alway and fellow workers have recently done a considerable amount of work on the subject, and have endeavoured to correlate the values obtained with various physical "constants" of the soil. The results are discussed below in the appropriate section. It is of interest to note here some maximum and minimum limits of moisture content under various field conditions. Widsøe and McLaughlin<sup>2</sup> working in Utah found that the maximum

<sup>1</sup> Ref. p. 45.

<sup>2</sup> *Utah Sta. Bull.*, No. 115 (1912), p. 195.



amount of water held by the soil against gravity under field conditions was about 24 per cent. (on dry weight) and the minimum amount about 8 per cent. except in the top foot, where it was less.

Determinations made by Russell<sup>1</sup> show how differences in organic content affect the amount of water held by the soil. The figures are expressed as volume percentages (Table IV).

Table IV.

*Relation of water content to loss on ignition (Russell).*

Rothamsted soils	Loss on ignition	Volume of water	
		In normal moist state	After period of drought (1909 and 1910)
Poor heavy loam ...	4.3 %	23.2	17.0
Heavily dunged arable soil	10.0	30.3	20.0

(d) *Capillary movement of soil water.*

The capillary movement of soil water may take place in all directions. The majority of the investigations deal with the upward movement of water, and less work has been done either on downward or lateral movement.

The general subject of the effect of capillary forces in causing movement of water in the soil is examined by Alway and McDole<sup>2</sup>. Very diverse views on the subject have been expressed by different workers, some of whom consider that the water may come from very great depths. Mitscherlich<sup>3</sup> as the result of an indirect calculation from experiments on the "heat of wetting" of soils finds the enormous value of 2 to 3 kilometres for heavy clay soils. He considers this value to be of no practical importance and his experimental values do not exceed 80 cms. over a period of three months. Leather<sup>4</sup> from field studies in India during the dry period, concludes that the maximum distance over which water moves upward towards the surface is very limited and does not exceed a few feet. A series of determinations made by him of water present in varying depths of soil over a period of 9 months is given in Table V. The rapid loss of water from the third and fourth foot can hardly be attributed to belated drainage, because the soil below 4 feet is losing water at the same time. There is a small, but definite, loss from the fifth and sixth feet depths, while that from the seventh foot is scarcely perceptible.

<sup>1</sup> Russell, E. J. *Soil Conditions and Plant Growth*, 3rd ed. (1917), p. 140. Longmans.

<sup>2</sup> *Journ. Agric. Res.*, **9** (1917), p. 27.

<sup>3</sup> *Landw. Jahrb.*, **30** (1901), p. 361.

<sup>4</sup> *Mem. Dept. Agric. India*, Chem. Series I (1908), p. 79.

Table V.

*Weight in lb. of water present at different times in varying depths of soil (Leather).*

pth	19th Sept.	20th Oct.	30th Nov.	8th Jan.	15th Feb.	27th Mar.	6th May	5th June	15th Jun
foot	18.97	15.78	14.21	12.15	12.10	14.18	10.83	13.87	10.41
feet	—	19.27	17.95	18.17	18.79	19.02	16.39	15.40	15.38
..	24.75	18.84	19.68	11.95	12.00	10.51	10.35	9.67	9.03
..	25.95	17.51	18.35	13.54	11.27	9.27	6.55	6.63	6.36
..	25.65	23.69	21.91	21.07	20.18	19.56	18.10	16.20	16.64
..	26.42	25.00	21.50	24.00	23.54	22.45	20.82	19.45	18.99
..	26.42	26.00	25.00	25.00	25.30	25.26	24.50	23.10	24.00
d	169.12	146.69	133.00	125.88	123.18	120.85	107.57	104.32	100.81

The present writer<sup>1</sup> has shown that Slichter's<sup>2</sup> values for the dimensions of the triangular capillary tubes in an "ideal" soil, made up of spheres of one radius packed in the closest possible manner, may be employed to calculate the probable maximum capillary rise. The relation deduced is

$$h = \frac{.75}{R}$$

where  $h$  = height of liquid,  $R$  = radius of soil particle.

The average rise in feet for ideal soils of various grain size is shown in Table VI below:

Table VI.

*Capillary rise in ideal soils of various grain size (Keen).*

Soil fraction	Dia. in mm.		Average capillary rise in feet
	Max.	Min.	
Fine gravel ...	3	1	$\frac{1}{3}$
Coarse sand ...	1	.2	$1\frac{1}{2}$
Fine sand ...	.200	.010	7 $\frac{1}{2}$
Silt ...	.040	.010	31 $\frac{1}{2}$
Fine silt ...	.010	.002	150
Clay ...	.002	—	150 upwards

The possible height increases considerably with diminution in particle size and may theoretically be infinite. In actual soils there is no possibility of a high value for the capillary rise except in those containing a large amount of clay, and in this case the swelling of the colloidal portion due to the imbibition of water will close many of the capillary tubes and reduce others to such a small diameter that movement of water will be exceedingly slow. Hence in practice we should not expect to find the

<sup>1</sup> Keen, B. A. *Journ. Agric. Science*, 9 (1918-19), p. 396.

<sup>2</sup> King and Slichter, *loc. cit.*

values for the capillary rise in soils of different textures approaching the theoretical ones given in the table.

A further complication in soils is that the percentage of moisture in the column decreases with increasing distance from the source, i.e. the whole of the moist soil is not saturated. This may be due to one or both of two causes: at considerable distances from the source, water can ascend only through the finer channels in the soil, and thus the average water content in the layer will be short of the saturation value; the water may be present as a film over the surface of the soil particles and the capillary channels therefore not completely full. The motion of the water in this surface film would be very slow on either of the two hypotheses considered in this paper.

Although the capillary rise in fine grained soils exceeds that in coarse grained, the rate of rise is less, the equilibrium being reached more rapidly in the soils of open structure. The experiments of Loughridge<sup>1</sup> are typical of the many investigations. Less attention has been given to rate and amount of downward penetration of moisture. Alway and McDole<sup>2</sup> have studied the rate of both upward and downward movements of water in soils of varying original moisture contents and have compared the values obtained with the hygroscopic coefficients<sup>3</sup> of the soils. Generally speaking their results are similar to those of Atterburg<sup>4</sup> in that no consistent relationships could be discovered. The rate of downward penetration, while showing little dependence upon the hygroscopicity, increased with the amount of initial moisture content. The rate of capillary rise, on the other hand, was not so definitely connected with original moisture content, neither could any relation between it and the hygroscopic coefficient be traced.

In any attempt to correlate data of capillary rise and downward penetration with the soil conditions the use of the hygroscopic coefficient is not, by itself, sufficient. As shown in the section dealing with hygroscopicity, this is essentially a surface phenomenon, and although the capillary effects will vary with the nature of the soil grain surface, they will also directly depend on the extent and size of the pore spaces in the soil. Measurements of permeability, etc., on the lines of Green and Ampt quoted above, together with applications of the mathematical and experimental investigations of Buckingham<sup>5</sup> are all needed for the satis-

<sup>1</sup> *California Expt. Sta. Rept.* (1892-4), p. 91.

<sup>2</sup> *Journ. Agric. Res.*, **10**, (1917), p. 391.

<sup>3</sup> *Landw. Vers. Stat.* **69** (1908), p. 53.

<sup>4</sup> *U. S. Bureau of Soils, Buls.* **25** (1904) and **38** (1907).

<sup>5</sup> See footnote, p. 50.

factory interpretation of data on capillary rise, or downward penetration, of water in soils.

King<sup>1</sup> did some experiments on lateral diffusion in surface soils, by maintaining a constant water level at one corner of a shallow square box of soil and determining the moisture content at intervals along the circumference of circles described with the corner as radius. He found that the lateral movement did not extend much beyond 3 feet in 31 days. No absolute value for the lateral movement can be obtained from these experiments, as evaporation into the air from the soil surface was not prevented. Some interesting work by Müntz and Gaudechon<sup>2</sup> on the diffusion of salts in the soil has a bearing on the present subject. They placed known amounts of various fertiliser salts in different positions in a box of soil, and determined the subsequent distribution of these salts. Surface evaporation was prevented and experiments were also done on the influence of rain—both natural and artificial—on the distribution of the salts. Diffusion was found to be very slow, especially in a lateral direction. Müntz and Gaudechon attribute this to the absence of a continuous medium for diffusion, in other words, the soil water is mainly present as a film over the particles, in which case both the diffusion of salts within it, and its own movement, would be very slow. Even under the influence of considerable amounts of rain the downward diffusion of the salts is slow, owing to the small value for downward percolation imposed on the soil water by the minute capillary spaces.

The whole question is extremely complicated, as a close relation exists between surface and capillary effects in soils, and any variation of one affects the other. Patten and Waggaman<sup>3</sup> show that where the disturbing influences are not great, e.g. in quartz sands and similar materials, the time rate of absorption of dyes and various salts, and the distribution of these materials between solid and liquid can be expressed by the usual mathematical formulae applicable to such studies. But in practice the disturbing influences are important. A detailed study was made of one aspect—the change in the physical character of the soil itself consequent upon absorption of dissolved materials. The flocculated structure induced by acids and lime and the deflocculation with alkali, for instance, were shown directly to affect such physical factors as the drainage conditions, aeration, and the capacity of the soil to hold the soil solution and control its movement through the soil.

<sup>1</sup> *Wisconsin Agric. Expt. Station*, 7 (1890), p. 145.

<sup>2</sup> *Ann. Sci. Agron.* (3 sér.) 4, 1. (1909), p. 379.

<sup>3</sup> *U.S. Bureau of Soils, Bull.* 52 (1908).

(c) *The hygroscopic moisture in soils.*

An excellent historical summary of work on hygroscopicity of soils is given in a paper by Alway<sup>1</sup> and again in conjunction with Kleine and McDole<sup>2</sup>, and hence need not be repeated here. The principle underlying the method is that the large total surface of the soil grains will, in an atmosphere of water vapour, absorb on the surface a film of water, and this process will continue until the vapour pressure of the film so formed is equal to that of the vapour in which the soil is placed, when equilibrium will be reached. Various methods have been used to determine this hygroscopic coefficient. The practical difficulties are serious. It is difficult to maintain an atmosphere saturated with water vapour, and the effect of slight temperature and barometric changes is to cause additional condensation of moisture on the soil surface. Various methods have been devised, among which may be mentioned that of Rodewald and Mitscherlich<sup>3</sup>, in which the air-dried soil in a thin layer is placed over 10 per cent sulphuric acid in a vacuum desiccator, until equilibrium is attained, weighed, and then dried for 4 hours at 100° C. over P<sub>2</sub>O<sub>5</sub>, to obtain the dry weight. The difference between these two weighings is considered to give a measure of the total soil surface for the given weight of dry soil. 10 per cent. sulphuric acid was selected because in experiments with varying strengths, it was found to prevent the formation of dew, and at the same time allowed of the absorption of almost as much hygroscopic moisture as from water. Mitscherlich, in subsequent papers, developed the method to give further information on the soil character. He considers<sup>4</sup> that a determination of the soil surface by a hygroscopicity method gives a measure of the fineness of the soil type, without presupposing a definite form and the same specific gravity for the soil particles, and should therefore be superior to the ordinary mechanical analysis. He further develops his method to obtain information on the compound particles existing in soil of good tilth, which are of course broken down to their ultimate grains in a mechanical analysis. The 10 per cent. sulphuric acid is replaced by an organic liquid of high molecular weight, which is supposed to condense only on the *outer* surface of a compound particle, whereas water vapour condenses on the inner surface as well. Mitscherlich considers that the value given by the organic liquid experiments relates to the mechanical state of the

<sup>1</sup> *Nebraska Agric. Expt. Station Res., Bull.* **3** (1913).

<sup>2</sup> *Journ. Agric. Res.*, **11** (1917), p. 147.

<sup>3</sup> *Lander. Vers. Stat.*, **59** (1904), p. 433.

<sup>4</sup> *Ztsch. Angew. Chem.*, **23** (1910), p. 1840.

soil and ease of working, while the sulphuric acid determination can be regarded as a measure of the soil productiveness. His earlier views have apparently changed, because he previously states<sup>1</sup> that the hygroscopicity is of no importance from the standpoint of plant growth, but later on he asserts that hygroscopicity and the yield are related by the law of minimum (ref. 4, p. 56). These experiments were made with mustard plants grown in sand with varying additions of peat. The cause of this change of view is probably connected with his investigation on this law<sup>2</sup> which shows that its verification necessitates more exact data than are obtained by ordinary fertiliser experiments. The Helbrigel sand culture method is advised.

Mitscherlich's method is promising, and his attempts to distinguish "outer" and "inner" surfaces in soil aggregates is worthy of attention. The condensation of moisture on the grain surface is, however, a complex phenomenon, because this surface may vary in any one experiment, from that presented by quartz sand to a typical gel, the latter of course imbibing water vapour and swelling during the experiment. It follows that any preliminary treatment of the soil affecting the soil colloids may have a corresponding influence on the value of the hygroscopic coefficient. For this reason Ehrenberg<sup>3</sup> considered that the preliminary air-drying of the soil in Mitscherlich's method reduced the surface, especially where the percentage of humus was high; he therefore suggested the use of undried soil. Mitscherlich and Floess<sup>4</sup> contend that these colloidal changes are eliminated, or at any rate rendered negligible by the establishment of the vapour pressure equilibrium when the dry soil is exposed to 10 per cent.  $H_2SO_4$ . In a later paper<sup>5</sup> they examine the Ehrenberg-Pick modification of their method and find it unreliable owing to the time required by an experiment: and, as would be expected, the hygroscopicity varies with the original water content. Changes in the surface area of the soil could not be measured.

A large amount of work on the hygroscopic coefficient has been done in America, the method used being the well-known one devised by Hilgard<sup>6</sup>, many years ago, in which water is employed, instead of 10 per cent. sulphuric acid. American investigators use the hygroscopic coefficient thus found not only as a measure of relative fineness of texture.

<sup>1</sup> *Fähling's Landw. Ztg.*, **54** (1905), p. 673.

<sup>2</sup> *Landw. Vers. Stat.*, **75** (1911), p. 231.

<sup>3</sup> *Ztsch. Angew. Chem.*, **23** (1910), p. 1841.

<sup>4</sup> *Landw. Jahrb.*, **40** (1911), p. 645.

<sup>5</sup> *Inter. Mittl. Bodenk.*, **2** (1912), p. 463.

<sup>6</sup> *Amer. Journ. Sci.*, **7** (1874), p. 9.

and also for calculating the approximate amount of water available for ordinary crop plants, which, according to Alway<sup>1</sup>, is the difference between total moisture content and hygroscopic coefficient. Hilgard at various times investigated the limits of accuracy of his method, which has also been studied by other workers. Contradictory conclusions have resulted from incomplete or super-saturation of the atmosphere, and the absence of any accurate control of temperature. For purposes of field observations of moisture, etc., of different soils this lack of accuracy is unimportant providing reasonable care is maintained.

Although a large amount of work has been done on the hygroscopic coefficient of soils, only a small proportion of it has aimed at ascertaining which portion of soil constituents is mainly responsible for absorbing moisture, and a still smaller proportion on the mechanism of this absorption. The idea underlying most of the investigations has been to consider the value of the hygroscopic coefficient of the soil as a whole, as a measure of the average power of that soil to absorb moisture. But it is obvious that the different portions of the soil complex may take up moisture in very different ways, as mentioned above (p. 57). There will be a certain amount of surface condensation, analogous to the deposition of surface films studied by Rayleigh<sup>2</sup>, Trouton<sup>3</sup> and others, on the non-colloidal portion of the soil; the colloidal material will give rise to a large range of adsorption and imbibition effects; and there is the probability of chemical combination, or hydration, especially in the organic matter. Luxmoore<sup>4</sup> has made a good pioneering investigation on the varying factors making up the total hygroscopicity, employing for the purpose a large number of Dorset soils, and using the correlation method. The experimental methods employed were not very refined but the general conclusions to which they lead are probably correct.

He finds that the joint effect on the hygroscopic capacity of organic material and mineral particles is more than additive, and is probably due to the organic material being more effective than the coarser particles in keeping the smaller particles apart and free to exercise surface attraction. Table VII shows the amount of water found in five soils placed over atmospheres of increasing humidity, compared with the amount calculated from the contents of their respective soil fractions. It will be seen that the former is in excess in nearly every case.

<sup>1</sup> *Nebraska Agric. Expt. Sta. Res. Bull.*, **3** (1913).

<sup>2</sup> *Phil. Mag.*, **30** (1890), p. 285, p. 456.

<sup>3</sup> *Proc. Roy. Soc.*, **77 A** (1906), p. 292; **79 A** (1907), p. 383

<sup>4</sup> *Journ. Agric. Science*, **1** (1905-6), p. 304.

Table VII.

*Comparison of experimental and calculated water contents for five soils over atmospheres of increasing humidity (Luxmoore).*

Soil number	...	17		28		29		27		30	
		Calcu- lated	Found	Calcu- lated	Found	Calcu- lated	Found	Calcu- lated	Found	Calcu- lated	Found
Normal Atmosphere		1.44	2.23	1.55	2.24	1.02	1.50	.51	.81	.32	.42
Moist	" ...	2.90	3.75	2.85	3.84	2.30	2.84	1.17	1.48	.69	.82
"	" ...	4.37	5.22	4.55	5.63	3.62	4.12	1.76	2.11	1.17	1.11
"	" ...	4.80	6.13	5.23	6.44	4.01	4.36	1.88	2.33	1.31	1.01
Very moist	" ...	6.21	8.00	7.23	7.72	5.86	5.65	2.62	2.39	2.45	1.14

The organic substance in different soil fractions has apparently not identical hygroscopic power, and a similar remark applies to mineral particles of the same size in different soils. While increasing fineness of particles results in an increase in hygroscopic capacity, the experimental data do not show that this increase is proportional to the additional surface presented. Luxmoore explains this by supposing that the smaller particles during their formation from the larger ones by fracture and attrition, tend to become more nearly spherical, and will therefore offer less surface than if they were reduced images of the larger ones.

The relations between the hygroscopic coefficient and the "heat of wetting" of soils have been investigated to a certain extent. This latter phenomenon has been ably studied by Müntz and Gauduchon<sup>1</sup>. They

Table VIII.

*Heat evolved on wetting a soil and its component fractions (Müntz and Gauduchon).*

Soil fractions (after Kopecky)	Percentage of fractions present in soil	Heat evolved by one kilo. of each fraction	Calculated heat evolution for per- centage of fraction present
Coarse sand, >1 mm.	11.30	0.0 kilo-calories	0.0 kilo-calories
Fine sand, .1-.05 mm.	16.32	0.26 "	0.04 "
Sandy silt, .05-.01 mm.	44.89	0.64 "	0.28 "
Clay silt, <.01 mm.	27.29	3.1 "	0.84 "
Total	100		1.16

Experimental value for the soil 1-14.

find that the greater part of the observed heat evolution when water is added to soil, is due to the clay fraction as shown in Table VIII. The organic matter weight for weight is even more effective although its effect

<sup>1</sup> *Ann. Sci. Agron.* (3 sér.), 4, II, (1909), p. 393.



is masked somewhat by the small percentage present in soil. The ultra-microscopic or colloidal portion of the clay is shown to be responsible for the greater amount of the heat evolved. But the phenomenon is not entirely a physical one; something else is evolved besides adsorption effects, for if the soil is moistened with alcohol, benzene, etc. instead of water, the heat evolved is small in comparison (see Table IX). If mixtures of

Table IX.

*Heat evolution of soil fractions of increasing fineness in various liquids*  
(Müntz and Gaudechon).

No. of fraction	Heat evolved per kilo, in		
	water	benzene	toluene
1 (coarsest)	0.36	0.22	0.17
2	0.44	0.27	0.16
3	0.95	0.46	0.42
4	3.28	0.76	0.85
5 (finest)	4.84	1.28	—

alcohol and water are added, the amount of heat evolved is again considerable, and in all cases the density of the solution decreases, i.e. water is abstracted from the solution by the substance, especially when the latter is organic. Müntz and Gaudechon conclude that the heat effect is probably mainly due to chemical combination. Bonyoucos<sup>1</sup> studied the heat of wetting from a slightly different standpoint and arrived at conclusions in substantial agreement with Müntz and Gaudechon. Mitscherlich<sup>2</sup> did some preliminary work on the relation between heat of wetting and the hygroscopic coefficient of the soil, but could find no apparent connection. The whole subject could profitably be re-opened in the light of present knowledge of colloidal phenomena.

#### (C) ATTEMPTS TO OBTAIN A MORE COMPLETE THEORY OF SOIL MOISTURE RELATIONS.

A salient point brought out by a study of the above sub-sections is that each one is more or less detached from its neighbours. It has been recognised for some time that this division of soil moisture fails to give a complete picture of the *continuous* processes operative between the soil and its moisture content when the latter changes over wide limits. This has led to a number of investigations—mainly by American workers—in which an attempt is made to give more precision to the relation of varying moisture content to soil texture and plant growth.

<sup>1</sup> *Mich. Agric. Coll. Tech. Bull.*, **42** (1918).

<sup>2</sup> *Journ. Landw.*, **46** (1898), p. 255; **48** (1900), p. 71.

These investigations have followed, in the main, two lines. The divisions of soil water discussed in the preceding paragraphs, have been amplified by additional "equilibrium values" of soil water under defined conditions, and attempts have been made to discover inter-relationships between these values.

Among these investigations may be mentioned those on the "wilting coefficient"—defined as the amount of water remaining in the soil when permanent wilting of the plant occurs—by Briggs<sup>1</sup> and others, in which an attempt is made to correlate the requirement of the plant for water and the power of the system soil plus water to supply it; the "moisture equivalent," also due to Briggs<sup>2</sup> and fellow workers, defined as the amount of water retained in soil after subjection to a centrifugal force, 3000 times the gravitational force. This force is supposed to remove the water held in the larger capillary spaces of the soil; the amount of water then remaining—the moisture equivalent—gives a better quantitative comparison of soils than the water retaining capacity mentioned above. This amount of water is correlated with the soil texture as determined by the usual mechanical analysis. It is found that for a typical and well defined series of soils in which the material is mainly derived from the same geological source, the relation existing is given by the equation:

$$0.4 C + 0.59 D + 0.53 E = M \therefore 1.1,$$

where  $M$  = moisture equivalent,

$C$  = percentage of particles .05-.005 mm. in diameter,

$D$  = " " " below .005 " "

$E$  = " " " organic matter.

For other series of soils, the values of the numerical coefficients are, of course, different.

The influence of particles of larger size than group  $C$  is apparently very small and may be neglected. A change of 50 per cent. in the amount of coarse sand amounts generally to a change of only 1 per cent. in the moisture equivalent. Further work on the relation between the moisture equivalent and the mechanical analysis seems to show that no general formula is universally suitable, a modification having to be made for each soil type. This has been pointed out by Alway<sup>3</sup> in a paper embodying an examination of Briggs and Shantz<sup>4</sup> indirect methods for determining

<sup>1</sup> Briggs, L. J. and Shantz, H. L. *U.S. Bureau Plant Ind., Bull.* **230** (1912).

<sup>2</sup> Briggs, L. J. and McLane, J. W. *U.S. Bureau of Soils, Bull.* **45** (1907).

<sup>3</sup> *Journ. Agric. Res.*, **6** (1916), p. 833.

<sup>4</sup> *Loc. cit.*

the wilting coefficient. The latter investigation resulted in a series of ratios for the indirect calculation of the wilting coefficient from either the mechanical analysis, moisture holding capacity, moisture equivalent or hygroscopic coefficient (Table X). Alway, in the paper cited, examined the various indirect values for the hygroscopic coefficient,

Table X.  
(Briggs and Shantz.)

(The second term in the brackets shows the probable error of the relationship.)

Wilting coefficient	=	moisture equivalent
		1.84 (1 ± 0.007)
"	=	hygroscopic coefficient
"		.68 (1 ± 0.018)
"	=	moisture holding capacity <sup>1</sup> - 21
"		2.60 (1 ± 0.021)
"	=	0.01 sand + 0.12 silt + 0.57 clay <sup>2</sup>
"		(1 ± 0.025)

<sup>1</sup> Hilgard's method. *Soils* (1906), p. 209. New York.

<sup>2</sup> { Sand .2-0.5 mm. in diameter.  
Silt .05-.005 " "  
Clay <.005 " "

obtained by proportionally altering the above ratios in the necessary manner, and showed that caution was necessary in their use, owing to the influence of soil type on the ratios. Other results of Alway<sup>1</sup> cast doubts on the validity of the conception of a wilting coefficient, in its original form at least, because it is shown that plants can utilise approximately all the water in soil down to the hygroscopic coefficient, which, according to the above mentioned ratios of Briggs, is only about .7 times the wilting coefficient. Some results obtained by Shull, and Bouyoucos, and referred to in more detail later point in the same direction<sup>2</sup>.

Alway and McDole<sup>3</sup> have established a series of relations between the moisture equivalent, the hygroscopic coefficient, and the water retaining capacity. They find with certain loams of known hygroscopic coefficients, that the amount of water retained bears a relation to the hygroscopic coefficient, being from 2.1 to 3.1 this value according to the particular

<sup>1</sup> Ref. I, p. 58.

<sup>2</sup> For a detailed summary of work on the wilting coefficient, which lies rather outside the scope of the present paper, see V. H. Blackman (*Journ. Ecology*, 2 (1914), p. 43). The papers of Alway and Shull should also be read in this connection.

<sup>3</sup> *Journ. Agric. Res.*, 9 (1917), p. 27.

soil (Table XI), while its relation to the moisture equivalent is somewhat closer—0.8 to 1.01 (Table XII). An important result, shown by Table XI,

Table XI.

*Ratio of water content to hygroscopic coefficient for five soils, arranged in 2" layers and in different orders in a draining cylinder (Alway and McDole).*

Order of soils	Ratio	Order of soils	Ratio
L	2.1	A	2.4
J	2.4	D	3.1
H	2.9	H	3.0
D	3.1	J	2.5
A	2.3	L	2.1

Table XII.

*Ratio of final water content in the surface 3" section of loams to the moisture equivalent (Alway and McDole).*

Soil	Final water content 1-3 ins.	Moisture equivalent	Ratio	Soil	Final water content 1-3 ins.	Moisture equivalent	Ratio
A	26.2	29.5	0.88	H	17.1	19.7	0.87
B	24.2	25.8	.94	I	15.1	16.8	.90
C	22.2	24.1	.92	J	11.7	13.5	.87
D	22.0	27.8	.82	K	7.4	7.5	1.00
E	19.6	22.5	.87	L	5.8	7.2	.86
G	16.8	21.2	.80	M	8.0	7.9	1.01

is that if a draining soil column is made up of successive layers of soils differing in texture, the order of their arrangement exerts no influence on the final water content of each layer. An apparent anomaly is shown when a layer of coarse sand or gravel is interposed in the soil column. The layers of soil above the sand then show a higher moisture content than when they are in direct contact with the subsoil into which drainage takes place. It is well known that a gravel or sand subsoil in the field tends towards a better drainage of the surface soil. Any considerable mass of water in the surface soil is able to escape more quickly, other things being equal, owing to the larger size of the pores in the gravel subsoil. But when the moisture content is sufficiently reduced to bring the capillary pull into prominence in distinction to the mere gravitational drainage, then the layer of coarse sand effectively breaks the capillary tubes and the downward movement of the water is slowed up very considerably. If these results are correct the logical conclusion would be that the effect of a sand layer is to cause a more rapid initial drainage

from a wet soil, but to leave a higher final moisture content in the surface soil. On the other hand, a finer textured subsoil, although giving a slower rate of initial drainage, will give a lower final value for the surface soil moisture owing to the persistence of the capillary pull in the subsoil.

It will be seen that while most of the above investigations attempt to define, either completely or partially, the relations between the soil and the moisture content, they are mainly applicable over some small range of moisture content, or to some approximate equilibrium value. These values are of course interesting and important, but they do not lead to any clear conception of the laws holding between the soil and its water content, when the latter varies between and through these equilibrium values. Investigations of a different type are necessary for this purpose, and the most promising lines are summarised in the succeeding section.

#### (D) SURFACE FORCES IN SOILS AND THE COLLOIDAL HYPOTHESIS.

It will be realised from the facts presented in the preceding sections that any consistent explanation of the varying facts observed must take into account the intimate relations existing between soil moisture and the soil grains over a wide range of water content. It cannot be said as yet that we have a complete knowledge of these relations, and the various papers mentioned in this section should be regarded as indicating lines along which the problem may be attacked.

By far the most important soil constituents in any examination of surface forces are the clay and the humus. Recent work of Tempany<sup>1</sup>, in which the shrinkage was measured of various soils, previously moistened and worked into a condition of maximum plasticity, gives a valuable insight into the connection between colloidal portions of the soil and the water content. A linear relation is found to exist between the linear shrinkage and the pore space in the contracted (oven-dried) soils, for soils of widely differing mechanical analyses (Fig. 2). The pore space in the contracted soil decreases with increasing content of colloidal clay. Tempany's method enables an estimate to be made of the amount of total clay which exists in the colloidal state, provided certain probable assumptions are made, for which the original paper should be consulted. The percentage works out to a much greater value than that given by the earlier methods of Schloesing<sup>2</sup> or the later determinations on the same lines by Ehrenberg and Given<sup>3</sup>, where the amounts are about 1 per cent.

<sup>1</sup> *Journ. Agric. Sci.*, **8** (1916-17), p. 312.

<sup>2</sup> *Encyclopédie Chimique*, Frémy (Paris, 1885), **10**, p. 67.

<sup>3</sup> *Koll. Zeit.*, **17** (1913), p. 33.

only (see Table XIII). In this latter method the clay is acidified and washed to remove calcium and magnesium salts, and then allowed to settle over a long period in water to which a little ammonia has been added. The colloidal material remains in the supernatant liquid. These sedimentation methods, however, do not give a quantitative value for the amount of colloidal material present in clay. On the provisional hypothesis mentioned earlier, that the soil grains are coated more or less

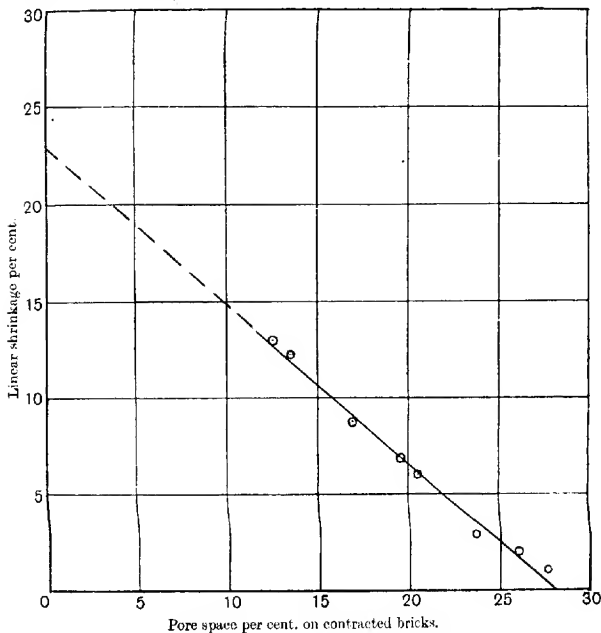


Fig. 2. Relation between pore space and linear shrinkage (Tempany).

with colloidal material, one would not expect more than a fraction of it to remain in suspension. A considerable amount undoubtedly remains on the grain surface. Apparently no examinations have been made by any investigators of the clay after this 1 per cent. colloidal material has been removed, to see if any great alteration has taken place

in its properties. A determination on these lines would show at once whether the 1 per cent. in suspension represents the bulk or only a fraction of the colloidal clay.

Table XIII.

*Proportion of total fine silt and clay, and colloidal clay in various soils*  
(Tempany).

Soil	Linear shrinkage per cent.	Content of fine silt and sand as determined by Osborne's beaker method <sup>1</sup> per cent.	Content of colloidal clay calculated from linear shrinkage per cent.
A	13.0	59.3	55
B	12.1	60.6	51
C	8.8	45.0	37
D	6.0	42.1	25
E	2.9	33.5	12
F	2.0	32.3	9
2	2.7	25.0	11
3	3.1	28.6	13
15	14.0	63.0	60
16	15.0	70.5	64

<sup>1</sup> Fine silt .01–.005 mm. in diameter.

Clay <.005 „ „

A knowledge of the amount of colloidal clay present in soils is certain to be of great use in studying soil relationships. For instance the effect of the small amount of pore space in a soil containing a high percentage of colloidal clay, will be operative over a wide range of moisture content, down to oven dryness, in modifying the movement of water and water vapour in the soil interstices. And again, a large amount of water will be present in the clay-gel, thus existing under very different conditions from the so-called “free water” in soil.

A study of the evaporation of water from this aspect has been made by the present writer<sup>1</sup>. It is shown that evaporation from soil and sand is very different in character. From the latter evaporation proceeds in accordance with the known laws of diffusion, and the results confirm the deductions of Briggs<sup>2</sup> and Leather<sup>3</sup> in which the soil is regarded as a framework of mineral particles. But when proper experimental methods are employed the evaporation from soil follows a very different course. A mathematical examination of the evaporation curves shows that two factors are operating over the whole range of water content. Judging by the hygroscopic coefficients of those American soils comparable with

<sup>1</sup> *Journ. Agric. Sci.*, **6** (1914), p. 456.

<sup>2</sup> *U.S. Bureau of Soils, Bull.* **10** (1897).

<sup>3</sup> *Loc. cit.*

the soils used in the writer's experiments, the initial percentage of water present was considerably above the hygroscopic coefficient, which therefore must be regarded as an equilibrium value of moisture content, and not solely as an expression of water present in one definite physical state. The controlling factor in the evaporation of the soil moisture is apparently not the organic matter *per se*, as the removal of the "soluble humus" by 2 per cent. NaOH makes very little difference. But when the colloidal property of the clay is destroyed by igniting the soil to a dull red heat the evaporation curve becomes identical with that given by sand, in spite of the fact that the ignited soil still contains a large number of very small particles<sup>1</sup>. It is in all probability the clay fraction, which, owing to its colloidal nature, profoundly modifies the process of evaporation. The effect is expressed in the equation deduced for the rate of evaporation by an expression of an exponential type, which, until further data are obtained on the relations existing between water content and other physical factors such as vapour pressure, must be regarded as empirical. The curve given by this empirical expression does not exactly fit the experimental one until allowance is made for the effect of the diminishing surface from which evaporation proceeds as the thickness of the moisture film diminishes. When this is done very good agreement is obtained over the whole range of moisture content used in the experiments. The actual general equation developed to express the two factors discussed above is:

$$B \frac{dw}{dt} = \sqrt{\left(\frac{ws}{100} + 1\right)} [2.303 \log (w + K) - \log_e K]$$

where  $\frac{dw}{dt}$  = time rate of evaporation.

$w$  = moisture content (percentage on dry weight of soil).

$s$  = specific gravity (true) of the soil.

$B$  and  $K$  = constants for each type of soil used.

These results show that there is an intimate connection between the soil complex and its moisture content over a wide range. Some very interesting work of Shull<sup>2</sup> on the surface forces in soils emphasises this aspect of the question. Using *Xanthium* seeds, which have almost a perfect semi-permeable coating, and rapid moisture equilibrium adjustment, he obtained two sets of data: (1) by suspending the dry seeds over the vapour of sulphuric acid and water mixtures of varying strengths, employing Walker's equation<sup>3</sup> for the relation between vapour and

<sup>1</sup> The soils used in these experiments when ignited gave, on shaking the bottle, a cloud of fine particles, which floated away like smoke when the stopper was removed.

<sup>2</sup> *Bot. Gaz.*, **62** (1916), p. 1.    <sup>3</sup> *Introduction to Phys. Chem.* 7th ed. 1913. Macmillan.



osmotic pressures, he obtained the corresponding osmotic pressures for varying water content of the seeds when in equilibrium with the vapour; (2) the dry seeds were allowed to come to moisture equilibrium with soil moistened to different degrees, arrangements being made to ensure that the seeds came into contact in turn with every part of the moist soil. Having determined the percentages of moisture in the soil and seeds when equilibrium is attained, the corresponding osmotic pressure of the soil moisture at varying water contents is obtainable at once from the first set of data. Shull finds great differences in the surface forces for soil and sand. The surface forces for the soil used are of the order of a few atmospheres only, down to about 20 per cent. of water. At this point there is a rapid increase, until at a moisture content of 10 per cent. it is about 1000 atmospheres. Sand shows this rapid increase only at very low percentages when the surface film effect comes into play.

An indication of the value of an investigation such as the above may be gained by applying the results to the percentage of moisture in the soil at the wilting-coefficient. Shull shows, firstly, that the seeds take up nearly as much water at the wilting coefficient, as when placed directly into water, and that secondly, the force with which the soil particles withhold moisture from seeds (and plants) is not more than 3-4 atmospheres, whereas the average root-cell sap pressure at this point is about 7-8 atmospheres. The plant wilts although both the amount and pressure gradient of the soil moisture are in its favour. Shull concludes that the wilting coefficient therefore must be regarded as a measure of the water in the *plant* and not in the soil at the time of wilt. The cause of wilting is due to the slow movement of the soil moisture, the rate falling below that necessary to maintain turgidity of the cells of the aerial parts even under conditions of low transpiration.

These experiments of Shull, while showing that the surface forces existing between soil and water are considerable over a wide range of moisture content, are not in themselves conclusive proof that the colloidal nature of soil is mainly responsible for the observed effects. However, by attacking the problem from a different point of view, Bouyoucos<sup>1</sup> and fellow workers have obtained a large number of interesting data, the interpretation of which requires a recognition of the intimate relations between the soil complex and its moisture content. These papers fall naturally into two sections, the first dealing with the expansion of a

<sup>1</sup> The various papers discussed in this connection appear in *Michigan Agric. Coll. Expt. Station Technical Bulletins*, Nos. 24 (1913); 31 (1916); 36 (1917); 42 (1918); and in the *Journ. Agric. Res.*, 8 (1917), p. 195; 15 (1918), p. 331.

moist soil when freezing occurs, and the second, on the lowering of its freezing point under different conditions. In the first series a dilatometer was used, the moist soil being introduced into the bulb which was then closed and the free space filled up with ligroin. The dilatometer was then cooled down to definite temperatures, and from the observed rise in level of the ligroin, the amount of water freezing at any given temperature could be calculated at once. The method has been employed by Foote and Saxton<sup>1</sup> with inorganic hydrogels and they find that by no means all of the water present can be frozen at temperatures slightly below 0° C. In fact some of the water present could not be frozen even at as low temperature as - 78° C. The experiments led to the conclusion that the water could be broadly divided into three divisions: free water, capillary-adsorbed water and combined water. There was no definite line of demarcation between these three groups and more or less arbitrary temperature depressions were taken in classifying the total water content into the divisions, but the experiments clearly indicate that the forces existing between the water and the substances used are of a very close and intimate character.

Bouyoucos finds that similar conditions hold for soil, although the relative amounts of the three groups vary considerably. In sandy soils, for instance, the free water appears to predominate largely, the remainder being almost entirely combined water. In loams and silt loams the same conditions hold except that more water is present in the combined form, while in soils containing much clay and humus, the division is more equal among the three postulated groups of water content. Bouyoucos could obtain no quantitative agreement between the amount of water that failed to freeze, and certain of the experimental characteristics of soils, such as the mechanical analysis, moisture equivalent, hygroscopic coefficient and wilting coefficient, although in some cases, notably the last two, a qualitative agreement was found. This discordance is by no means surprising in view of Tempary's experiments, mentioned above, on the varying proportion of colloidal clay present in the clay fraction of soil, and when it is realised that such measurements, as the hygroscopic coefficient for instance, attempt to give a single-valued expression to what is in reality a complex set of variables.

Bouyoucos' second line of research—the depression of the freezing point of the soil-solution measured *in situ*—also indicates that very different relations exist between soil and its moisture content from those between sand and water. These experiments were done in the usual

<sup>1</sup> *Journ. Amer. Chem. Soc.*, **38** (1916), p. 588, and **39** (1917), p. 1103.

Beckmann apparatus, both on soil extracts and on the actual moist sands and soils themselves, i.e. on the soil solution *in situ*. The results show that for moist sands the product of the freezing point and the percentage of moisture is approximately a constant, in other words, the depression is inversely proportional to the concentration. Soils show a different behaviour, the freezing point depression increasing very rapidly with decrease in moisture content. The approximate relation is that the depression increases in geometrical progression as the moisture content decreases in arithmetical progression. The authors advance possible qualitative explanations of this difference, by assuming that in soils, part of the water is rendered unfree, in the sense that it takes no part in the freezing point depression of the soil solution, as measured by the Beckmann apparatus. The present writer<sup>1</sup> has been able to give this hypothesis a quantitative basis, and has shown by an examination of their experimental data that the total moisture, free, and unfree water are related by the equations:

$$Y_n = aM_n^x,$$

$$Z_n = \frac{1}{a^x} \cdot Y_n + Y_n,$$

where  $M_n$  = total moisture,

$Z_n$  = unfree „

$Y_n$  = free „

$x$  and  $a$  = constants.

The terms “free” and “unfree” in these expressions are used with the meaning Bouyoucos assigns to them: the free water contains in solution the various soluble salts, and follows the law for dilute solutions, viz., that the freezing point depression varies inversely as the concentration: the unfree water takes no part in the depression of the freezing point. It is pointed out by the present writer in the paper on the above quantitative relations that these definitions are provisional only, until further information is obtained on the possible physical—or chemical—differences in the two cases.

All the experiments discussed above have a direct bearing on the soil solution considered as the nutrient medium for plant growth. They show that the soil and soil solution are bound together by intimate relationships. A change in the moisture content is reflected in the resulting alteration of all the complex variables involved. Consequently,

<sup>1</sup> Keen, R. A. *Journ. Agric. Science*, 9 (1918-19), p. 400.

conclusions based on an examination of soil solution *after it has been removed from the soil*<sup>1</sup> cannot be regarded as necessarily quantitative, and it is open to doubt whether they are always qualitative. As a result some considerable controversy has been aroused, which has mainly centred around the deductions of Whitney and Cameron<sup>2</sup>, that the soil solution is very dilute and practically constant in composition. It is hardly necessary in the present paper to give an account of the various views expressed, as this has been done elsewhere<sup>3</sup>. The point which really needs emphasis in all studies of the soil solution is the recognition that the system soil + soil solution must be treated as a whole. This point is brought out in all the experiments discussed in this concluding section of the present paper. The relations between the soil and its moisture content are exceedingly complex, and considerations of surface films distributed over an inert mineral framework, such as sand-grains, are insufficient to explain the observed facts, for they give rise, as already noted in Sections (B) and (C) above, to a classification of soil moisture into more or less arbitrary and water-tight compartments.

On the other hand the papers discussed in this concluding section are characterised by the development of continuous relations between the soil and its moisture content. Study of the soil from the colloidal point of view appears to be the most promising way of obtaining further knowledge of these vital, but intricate, relationships.

<sup>1</sup> Summaries of the various methods of extracting soil solution are given by Stiles and Jørgensen (*Journ. Ecology*, **2** (1914), p. 245, and Bouyoucos (*Mech. Treb. Bull.*, **24** (1915)).

<sup>2</sup> U.S. Bureau of Soils, *Bull.* **22** (1903).

<sup>3</sup> A full account of work on the soil solution is given by E. J. Russell, in *Soil Conditions and Plant Growth*, 3rd ed. (1917), p. 104. Longmans. See also, by the same author, *Chem. Soc. Ann. Reports*, **15** (1918), p. 172 ("Agricultural Chemistry and Vegetable Physiology"), in which are discussed experiments at the University of California, giving results in opposition to the views of Whitney and Cameron.

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## THE DETERMINATION OF AMMONIA IN SOIL.

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### INTRODUCTORY.

It was early recognised that the figures for the ammonia in soils determined by distillation at atmospheric pressure with strong alkalies were too high, owing to the simultaneous decomposition of nitrogenous compounds. Various methods were devised to overcome the difficulty.

Schloesing used a strong alkali but worked at air temperature. The material to be analysed was mixed with an alkaline solution in a shallow dish and placed close to another similar dish containing a dilute acid. A bell-jar was put over the two and the ammonia slowly diffused from the soil to the acid. The method was at best tedious and uncertain.

Schloesing also proposed another method, according to which the ammonia was extracted from the soil with hydrochloric acid. The filtered extract was boiled with a strong alkali to separate the ammonia. It was assumed that all the ammonia was extracted by the acid and that no more ammonia was formed during the operations. It is now known that neither assumption is justified.

Boussingault suggested the use of magnesia to liberate the ammonia, either at atmospheric pressure or in a partial vacuum.

In 1910 E. J. Russell<sup>1</sup> investigated the subject more thoroughly and showed that even at low temperature and pressure nearly all the alkalies gave figures for ammonia which rose as the strength of the alkali was increased, and that there was therefore progressive decomposition of nitrogenous material. He found two exceptions. Magnesia did not give rise to much progressive decomposition because the low solubility made a strong solution impossible, and similar results were obtained with weak alcoholic potash. Russell accordingly suggested the use of these two methods as the best available at the time. Unfortunately when tested on soils to which a known amount of ammonia had been added they proved to be very inaccurate, the error varying from thirty to fifty per cent.

<sup>1</sup> *Journ. Agric. Sci.*, **3** (1910), p. 233.

Before and since the date of Russell's paper many others have been published giving the results of comparative tests of the various processes in use. No reference need be made to them here, as the present paper deals with the aeration process only. An exception must be made however in the case of a paper by Baragiola<sup>1</sup> and Schuppli, who used the magnesia process in an apparatus essentially the same as that figured by Russell, and obtained a quantitative recovery of added ammonia. On the other hand they state that the majority of soils examined by them were free from ammonia, a result so unlike those obtained at Rothamsted and elsewhere as to throw some doubt on the reliability of their method.

In 1914 Potter and Snyder<sup>2</sup> published an account of their experiments on the determination of ammonia in soil by the aeration method originally introduced by Folin for the analysis of physiological fluids. They made use of the apparatus recommended by Kober<sup>3</sup> for the determination of relatively large amounts of nitrogen such as occur in the Kjeldahl process. Twenty-five grams of soil were aerated with 50 c.c. of water and 2 grams of sodium carbonate in a 500 c.c. Kjeldahl flask, and the ammonia was absorbed in dilute acid in a 16 oz. bottle. With an air current of about 250 litres an hour they obtained good results by aerating for 15 to 19 hours, and added ammonia was recovered nearly completely, the error being as a rule less than two per cent. and generally on the side of defect.

The only objection to the process is the length of time required, which not only makes it impossible to carry out more than one set of determinations in a day but also introduces serious risk of high results in the case of soils rich in unstable nitrogenous substances. One of the soils examined by the writer of the present paper showed measurable decomposition in six hours on aeration with magnesia and sodium chloride solution.

With the aeration apparatus described below it is possible to recover large quantities of added ammonia with an accuracy of 98 to 99.5 per cent. in six hours and with a nearly equal accuracy in three hours, while for most agricultural purposes an aeration of one and a half hours is sufficient.

<sup>1</sup> Dr W. J. Baragiola and Dr O. Schuppli. "Die Bestimmung des Ammoniums im Boden u. s. w." *Die Landwirtschaftlichen Versuchs Stationen*, Band xc (1917), p. 123.

<sup>2</sup> Potter, R. S. and Snyder, R. S. "The Determination of Ammonia in Soils." *Toura Expt. Sta. Res. Bull.*, 17, October, 1914.

<sup>3</sup> Kober, P. A. and Graves, Sara S. "Quantitative Ammonia Distillation by Aeration for Kjeldahl, etc." *Ill. Journ. Amer. Chem. Soc.*, 35 (1913), p. 1394.

## APPARATUS.

The apparatus is shown in Fig. 1, which is drawn to scale. The soil is put in the aerator, *A*, a strong glass tube 83 cm. long and 23 mm. in diameter with an egg-shaped bulb blown on it about 18 cm. from the upper end. The air enters through the inlet tube, *B*, which has an internal diameter of from 3.5 to 4 mm., and passes through the rubber stopper at the lower end of *A* as close to the glass as possible. It is supported in a groove cut in the upper side of the cork block, *C*, which is cemented to

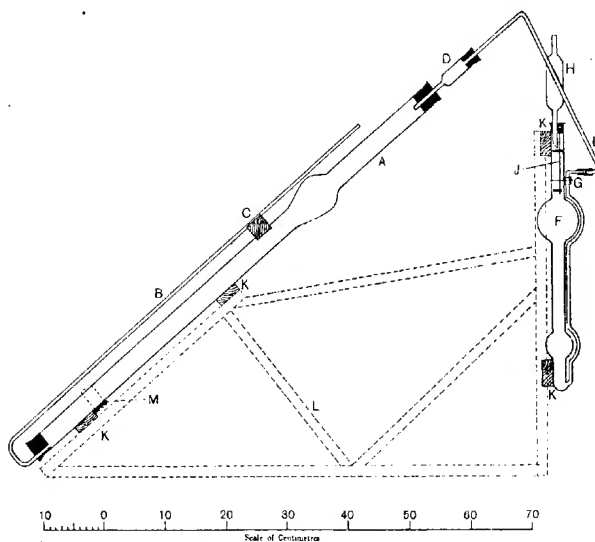


FIG. 1. One unit of the apparatus.

the aerator. Linen tape, not shown in the drawing, is bound firmly round the two tubes and the cork block. The inlet tube should fit in the groove loosely enough to allow of it and the stopper being withdrawn for one or two centimetres without unbinding the tape. The upper part of the inlet tube for 10 or 12 centimetres is bent to the right, upwards from the plane of the paper, at an angle of about  $10^\circ$  to allow of connection to the next set of apparatus. The upper end of the aerator is

closed by a rubber stopper carrying a funnel, *D*, which is loosely plugged with cotton wool to stop spray. *D* in its turn is connected with the absorber, *F*, by means of a rubber stopper and bent tube, *E*. If soft rubber stoppers are used there will be sufficient play to allow of the connections being made when both aerator and absorber are fixed in position. If any difficulty is experienced the tube *E* may be cut and joined by rubber tubing.

The absorber *F* is 40 cm. high and has an internal diameter of 17 or 18 mm. The capacity of the lower bulb is about 50 c.c. and of the upper bulb about 120 c.c. At the upper end is a rubber stopper carrying a splash-bulb *H*, the lower end of which is ground off diagonally. A glass rod, *J*, fixed in the stopper carries two rubber discs the diameter of which is slightly less than that of the inside of the absorber; they are cut from the end of a rubber stopper and serve to stop splashing.

The side tube of the absorber is supported by slipping over it a short length of thick-walled rubber tubing, *G*, split lengthwise, and binding it to the absorber with soft copper wire.

It is important that there should be no space left between the rubber stoppers and the walls of the tubes. The stoppers should be chosen as nearly cylindrical as possible, of soft rubber, and should be cut off at the point where they cease to touch the glass.

The drawing shows only one set of apparatus, but six may be used, the air passing through each in turn. A suitable stand for six may be made by constructing two wooden frames of the shape and dimensions shown by the dotted lines, *L*, and joining them by four cross-bars, *K*, about 92 cm. long. The aerators and absorbers are supported between blocks of cork glued and nailed to the four cross-bars (these blocks are not shown in the drawing). They are held in position by tapes (also not shown) fastened to the back of the cross-bars by drawing pins. To prevent the aerators from slipping down, wedges of cork or wood, *M*, are fastened to them by rubber bands which may be cut from wide tubing.

An aerator and its absorber do not lie in the same plane, but as shown in the drawing, each absorber lies slightly nearer the filter pump, that is, below the plane of the paper. It is then easy to connect the top of the splash bulb, *H*, with the inlet tube, *B*, of the next set of apparatus by a bent glass tube and rubber joints. The various joints should be made of the best soft rubber tubing wide enough to slip easily on to the glass. There is little danger of leakage as there is always reduced pressure inside.

The air entering the apparatus should be drawn from outside the laboratory and should be purified by passing through cotton wool, two



washers filled with dilute sulphuric acid, and again through cotton wool or glass wool to stop acid spray. An air current of 300 litres per hour is suitable and may be obtained with one large filter pump worked by water, or two of the ordinary size working side by side and connected with a large glass bottle to equalise pressure. Good results have been obtained with currents as low as 200 litres and as high as 400 litres of air an hour. If the current is too small the soil is not properly broken up, while too strong a current may lead to loss of acid from the absorber by splashing.

The apparatus is used as follows. In each absorber is put rather more *N*/50 sulphuric acid than it is expected will be required; if 25 grams of soil are taken, 1 c.c. of the acid is equivalent to 11·2 parts per million of ammoniacal nitrogen. A few drops of a 0·05 per cent. solution of methyl red in alcohol are added and then distilled water free from ammonia is poured in until the lower bulb is nearly full. The stoppers at the lower end of each aerator are withdrawn sufficiently to allow of a small plug of cotton wool being fixed loosely in the end of the glass tube, and are then replaced. Twenty-five grams of the soil, previously passed through a 3 mm. round-hole sieve, are weighed into each aerator; the cotton wool plugs prevent the inlet tube being blocked. Then 50 c.c. of the alkaline solution are added and about 1 c.c. of good paraffin lamp oil. The alkaline solution contains 108 grams of carbonate of soda crystals and 150 grams of sodium chloride per litre; it is best made up in large quantities and freed from ammonia as far as possible by passing a strong current of purified air through it for some hours. The blank should be carefully determined, and should not be more than equal to 0·10 c.c. of *N*/50 acid in 50 c.c. In special cases, which are mentioned later, about 2 grams of recently ignited magnesia and 50 c.c. of a 25 per cent. solution of sodium chloride are used instead. The first absorber is connected to the air pump, a slow current of air is started, and the various connections are made one after another from the pump outwards. The soil may move bodily up the aerator as a solid plug which however always breaks and flows back on reaching the bulb. As soon as this has happened the air current may be increased to full strength. In about five minutes the whole of the soil will be finely broken up. The acid in the absorber should fill the whole of the stem and the lower part of the bulb with bubbles if absorption is to be complete<sup>1</sup>. If it does not rise high enough, more water should be used, or a loose glass rod capped at the bottom with rubber and bearing

<sup>1</sup> The importance of ample scrubbing has been pointed out by B. S. Davison, *Journ. Indust. Eng. Chem.*, **10**, 8 (Aug. 1918).

two rubber discs similar to those fixed at the top of the absorber may be dropped into the tube, or finally a tube containing camphor may be inserted between the washers and the apparatus. This will cause the acid to break up into fine foam<sup>1</sup>; there is of course greater danger of losing acid by the carrying over of fine spray, so that particular attention should be paid to the rubber discs intended to stop this. After the aeration has been carried on for a sufficient length of time the air current is cut down as far as possible without actually stopping it and the connections are broken in turn beginning at the end farthest from the pump.

The titration is made with  $N/50$  sodium hydroxide and may be carried out in various ways. If the greatest accuracy is required it is best to proceed as follows. The upper stopper of the absorber is removed and the inside of the splash head and the glass rod and rubber discs are washed into a 200 c.c. flask of hard glass with a jet of water from a wash bottle. The bulk of the acid is then blown over into the flask through the side tube by applying the lips to the upper end of the absorber, but the latter is not washed out. Standard soda is then run into the flask until the colour of the indicator begins to change, when the liquid is poured back into the absorber and again blown back into the flask. The absorber is washed out twice with a little water. Owing to the absorber not having been washed out at first, the liquid will still be slightly acid. It is boiled for a few minutes to remove carbon dioxide, and the flask is closed with a rubber stopper carrying a guard tube filled with soda-lime and cooled under the tap. The titration is then completed.

If the greatest accuracy possible is not required, the following method may be adopted. A soda-lime guard tube is fitted to the wash bottle, and another to the top of the absorber so that no carbon dioxide enters it. The titration is carried out exactly as before, but the boiling is omitted. The results agree with those obtained by boiling to less than 9-10 c.c. of the acid, generally to 0.05 c.c. or less, and the saving of time is considerable. If this method is adopted the air should be passed through caustic soda before entering the sulphuric acid washers.

#### EXPERIMENTAL.

It is of course impossible to prove at present that any method for the determination of soil ammonia is absolutely correct. To do so it would be necessary to know every nitrogenous compound present in the soil and the extent to which it breaks down on aeration with an alkaline

<sup>1</sup> I am indebted for this suggestion to Mr E. M. Crowther who has been using the apparatus for some months in this laboratory with complete success.

substance, or else to find a soil free from ammonia and easily decomposable nitrogenous substances. In either case a known amount of ammonia could be added and the accuracy of the method checked by the completeness of the recovery. We certainly are far from knowing every nitrogenous compound in any soil, and it is very doubtful if there is any natural soil free from ammonia. It is true that Baragiola and Schuppli<sup>1</sup> state that the majority of soils examined by them by distillation in vacuo with magnesia were free from ammonia, but the writer has not yet found a soil which did not give up one or two parts of ammonia per million by the aeration method. Under the circumstances it is necessary to give a somewhat arbitrary definition to soil ammonia. Russell's<sup>2</sup> definition is that "a substance is called an ammonium compound if it evolves ammonia rapidly, completely and in one stage when treated with weak alkalis at low temperatures."

For the purpose of the present paper it is not necessary to modify the definition beyond adding that the aeration process shall be used and that the weak alkali shall be magnesia in 25 per cent. sodium chloride. In nearly every case the sodium carbonate solution will give the same result as magnesia.

The definition is clearly defective. Formamide for instance is slowly decomposed under the conditions of the analysis, and would be included under the head of ammonia. It is probable however that for most agricultural purposes such easily decomposed substances may be considered as ammonia without any serious error.

Accepting the definition of ammonia, the accuracy of the method has to be proved.

In the first place it was found that if pure carefully dried ammonium sulphate was treated in the apparatus, the ammonia could be recovered almost quantitatively. In the last pair of experiments made 2.778 mg. of ammoniacal nitrogen was added and 2.780 mg. and 2.769 mg. were recovered. If this amount had been present in 25 grams of soil it would have corresponded to 111.1 parts per million, with a recovery of 111.2 and 110.8, the greatest error being 0.3 parts per million.

The process was next tested on a number of different soils, in as fresh a condition as possible, that is, the analysis was generally begun within two hours of the taking of the sample from the field. All soils were passed through a 3 mm. sieve with round holes. The following were used:

1. Rothamsted soil, a rather heavy loam.
2. Rothamsted subsoil, a heavy clay.

<sup>1</sup> *Loc. cit.*

<sup>2</sup> *Loc. cit.*

3. Woburn light sandy soil. This had been bottled off about eighteen hours before analysis.

4. Two heavily dunged tomato-house soils.

5. A calcareous soil taken from the outcrop of the chalk on the edge of the Rothamsted plateau.

In the first place experiments were made by aerating the soils for three, six, and nine hours to check the agreement of the results *inter se* and to determine the effect of varying the time.

Carefully measured amounts of ammonium sulphate solution were then added to soils in which the natural ammonia was determined simultaneously, and the total ammonia was determined to test the completeness of recovery. In order that this may be a strict test of the accuracy of the method it is necessary that the ammonia should be in equilibrium with the soil as regards adsorption. This condition is not easy to fulfil without introducing other sources of error. If the soil be wetted with a solution of ammonium sulphate and allowed to stand for some time, over night for instance, two changes may take place owing to bacterial action. More ammonia may be formed, and some may be lost by oxidation to nitrites and nitrates. The most probable result would be a rise in the ammonia and the recovery would appear to be more complete than it really is. The addition of antiseptics does not get over the difficulty entirely. If the mixture of chloride and carbonate of soda were added at the same time it would almost certainly stop all bacterial and enzyme action, but at the same time it would alter the adsorptive power of the soil and in some cases would cause slight decomposition. Even such an indifferent substance as toluene appears able to raise the ammonia content of a soil in a very short space of time, possibly because it does not inhibit enzyme action while it stops nitrification. The method adopted has been to add the ammonia about two hours before beginning the analysis; bacterial action would not cause any important change in this time, while equilibrium would be nearly reached. The difficulty is probably not so great as it might appear at first sight. Theory requires that adsorption should be instantaneous provided that mixing is also instantaneous. The curves show that less than one-fifth of the ammonia is evolved during the first six minutes when 110 parts per million are present. In this time the soil is thoroughly broken up and the remaining four-fifths are then in equilibrium. The conditions are the same as if we were dealing with a soil containing naturally about twenty per cent. less ammonia.

The rate of evolution of the ammonia was measured and some of the

results are shown as curves in Fig. 2. In order to determine the rate, a small tap-funnel holding about 2 c.c. was sealed on to a vertical branch rising from the horizontal portion of the inlet tube of the absorber. A little acid, about one-tenth of the total amount which would be required, generally 1 c.c., was put in the absorber with the requisite quantity of indicator and water, and another similar quantity of acid in the funnel. A large Sugg's hourly-rate gas meter was attached outside the air-purifiers. The current was started and as soon as the indicator changed colour

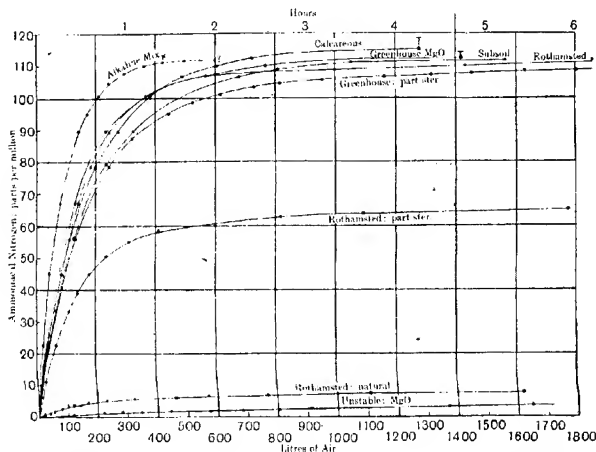


Fig. 2. Rate of evolution. Only a few of the points have been marked near the beginning. The short lines above the end of the curves marked "Calcareous" and "Greenhouse MgO" show the sum of the original and added amounts.

the acid in the funnel was allowed to flow into the absorber and the meter was read. The operation was repeated as often as necessary with decreasing amounts of acid. Towards the end the indicator changed very slowly and the readings were somewhat uncertain. When ammonia had been added so that the total was high,  $N/50$  acid was used, but when only a few parts per million were present  $N/250$  acid was substituted.

The curves are if anything a more convincing proof of the accuracy of the process than the simple recovery of added ammonia. This is so particularly in those for soils in which ammonia had been developed

slowly over a period of some weeks by partial sterilization, since in this case we may assume that equilibrium had been reached.

*Rothamsted Soil.* The soil was treated very easily in the apparatus; it broke up quickly and did not cake on the side of the tube. Duplicate analyses showed good agreement.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1.4	1.8	2.6	6.4	7.3	5.1	29.0	13.7
1.9	1.7	3.6	7.7	8.0	5.0	30.1	15.6

The two last samples contained solid ammonium sulphate: they were taken on different days from a field which had been recently top-dressed. With the addition of known amounts of ammonia the results were as follows:

Ammoniacal nitrogen in parts per million					
No.	Present in soil	Added	Total	Recovered	Percentage recovery
9	3.3	55.5	58.8	58.0	98.5
10	3.3	111.1	114.4	113.3	99.0
11	1.5	111.1	112.6	110.9	98.5

The soils were aerated for from five to six hours. In Exp. 11 the ammonia and alkaline mix had been added to the soil and allowed to stand over night.

The lowest curve for a Rothamsted soil shows the rate of evolution of ammonia from a natural soil. The amount present, over 7 parts per million, is unusually high and is probably due to the soil having been taken to a depth of about 3 in. only from a stubble after some days of very hot weather. Such conditions would probably hinder nitrification more than ammonification. The increase of 0.4 parts per million between 1107 litres and 1619 litres is doubtful, so that a sufficiently correct result could have been reached in about three hours or a little more.

The curve marked "Rothamsted; part ster." shows the rate of evolution from soil in which the ammonia had been slowly developing for some weeks as the result of the addition of about 60 parts per million in the form of an easily decomposable nitrogenous compound which would at the same time probably act as a partial sterilizer. The gradual increase of the ammonia in the soil had been watched by frequent analyses and the maximum was reached at the sample in question after which a slow fall set in. The curve is of interest because the ammonia would probably be in complete equilibrium with the soil. The aeration was carried on for three hours longer than the curve shows but no more ammonia could be detected with certainty, and 1000 litres of air gave

results accurate enough for all practical purposes. There is no sign of progressive decomposition.

The upper of the three curves marked "Rothamsted" shows the evolution from soil to which ammonium sulphate had been added so as to bring the total up to 112.6 parts per million. Aeration was carried on up to 2360 litres of air but only 110.9 parts were recovered, an efficiency of 98.5 per cent. At 1000 litres of air about 108.5 parts had been collected, 2.4 parts less than at 2360 litres, that is roughly only 2.4 parts passed over during the last 4.5 hours of the experiment.

*Rothamsted subsoil.* On account of its high clay content this soil might be expected to have considerable adsorptive powers. In three experiments in which ammonia had been added up to about 112 parts per million the recovery was 98.0, 98.3 and 98.6 per cent. The curve for one experiment is given in Fig. 2, and here again nearly all the ammonia was recovered with 1000 litres of air, aeration for 1.6 hours more producing only 0.7 p.p.m. of additional nitrogen.

*Woburn light sandy soil.* This had been in bottle in a damp condition for about eighteen hours before analysis. Ammonia was evolved very rapidly and its curve would lie nearer to that for "alkaline mix" than any of those drawn. It showed no signs of progressive decomposition; in one experiment 4.5 parts of nitrogen were evolved in six hours, and further aeration for three hours more produced a trace only, certainly less than half a part. In two experiments in which ammonia was added 98.5 and 98.8 per cent. of the total were recovered; in one of these 97.5 per cent. was recovered in three and a half hours.

*Tomato-house soils.* These had been used in the glass houses the previous year, receiving large quantities of stable manure, and at the end of the season had been thrown into heaps for use in pot experiments in partial sterilization. Owing to the size of the heaps and to their not having become airdried they may be considered fresh soils, but not in the sense in which the term can be applied to a soil taken directly from a field. They were somewhat more difficult to aerate properly as they clotted slightly on the sides of the tube just above the surface of the liquid.

One of the soils gave much the same results as those mentioned above. Direct determinations on the wet soil with the ordinary "alkaline mix" containing carbonate of soda gave the following results:

(1)	(2)	(3)
2.6	7.5	3.3
3.3	9.9	4.2
3.4	10.2	4.7

The differences for No. 2 are rather high. They may be due to defective sampling. The ammonia content points to rather active bacterial action, and the presence of large pieces of straw and such material made complete mixing very difficult.

The curve marked "Greenhouse; part. ster." refers to some of this soil which had been treated with a partial sterilizing agent free from nitrogen and allowed to stand for about two months in a large bottle. The ammonia was therefore in equilibrium with the soil. On aerating with 1000 litres of air 105.5 parts of nitrogen were found; at 1500, 107.7 parts, and at 1800 litres 108.6 parts. There appears to have been a slow evolution of ammonia from unstable nitrogenous material, but the error due to stopping at 1000 litres would not be great. In any case there does not appear at present to be any means of avoiding this slow decomposition.

A second glasshouse soil proved very unstable. On aerating with the "alkaline mix" it gave 3.9 parts in 3 hours, 5.4 parts in 6 hours, and 7.7 parts in 9 hours. Some of the soil which had been allowed to stand over night in the alkali and was then aerated for 9 hours gave 12.4 parts.

The soil was next aerated with magnesia and 25 per cent. sodium chloride solution. The results were better but progressive decomposition was still evident. The figures were at 3 hours 2.4 parts, at 6 hours 3.6 parts, and at 10 hours 5.4 parts; they are indicated in Fig. 2 by "Unstable: MgO."

Calcium carbonate was also used as the alkali. The results were independent of the time, but the recovery of added ammonia from a solution of ammonium sulphate was so poor, ten to fifteen per cent., that it was abandoned.

The curve marked "Greenhouse MgO" refers to this soil after the addition of about 110 parts of ammoniacal nitrogen. The recovery was 98 per cent. and there was little change after the first 1000 litres of air had passed.

With unstable soils such as this it is advisable to aerate with a definite amount of air, say 1000 litres, which can be easily determined by adding ammonia and drawing the evolution curve.

*Calcareous soil.* Soils high in chalk present greater difficulties than any of the foregoing, the recovery of added ammonia being less complete.

A soil taken in January at Basingstoke and high in moisture showed 3.2 and 3.0 parts of nitrogen on analysis. Ammonium sulphate was added to bring it up to 55 parts per million but only 90 per cent. could be recovered. Two other experiments failed to recover more than 86 and 88 per cent. The analyses were then repeated near a steam-heated



radiator, and very unexpectedly the recovery fell to less than 70 per cent. The soil was now no longer fresh enough to make it worth while carrying the experiments further.

Later the experiments were repeated on a soil containing 28 per cent. of chalk from an outcrop on the edge of the Rothamsted plateau. The sample was very dry and full of small fragments of roots and such material. Added ammonia was recovered to the extent of about 95 per cent. only.

A fresh sample of the same soil was analysed after passing through a 3 mm. round hole sieve and found to contain 3 parts per million of nitrogen. Ammonia solution was added to another portion to bring the nitrogen up to 110 parts, and 94 per cent. only was recovered. A third portion was finely ground before analysis, and from this 99 per cent. of nitrogen could be recovered. Lumps of chalk picked out and crushed also gave up 99 per cent. of added nitrogen without difficulty.

A fourth sample freshly taken gave 3.9 parts on soil passing the 3 mm. sieve and 5.5 parts on a finely ground portion. The analyses were repeated next day with the same result. Added ammonia was recovered to the extent of 96 per cent. from the coarse soil and 97 per cent. from the fine soil. The evolution curve for the latter is given in Fig. 2. It will be seen that the shape is similar to that of the others.

The addition of potassium oxalate did not increase the recovery. Many other experiments have been made on this soil which need not be described here as they do not throw any light on the problem. At present one can only say that on a finely ground soil the accuracy is fair. In summer fine grinding presents no difficulty, but with a wet soil it would be almost impossible.

Further experiments will be made with calcareous soils.

The effect of substituting magnesia with or without sodium chloride for the "alkaline mix" has also been studied. It was found that a soil allowed to stand over night with magnesia and water showed a considerable rise in ammonia. This may be attributed to bacterial action, the conditions being nearly an optimum. There is a chance of this taking place even during aeration so that the use of magnesia alone cannot be recommended.

Magnesia with strong sodium chloride, from 15 to 25 per cent. solution, also gave higher figures for ammonia on field soils than did "alkaline mix," but the difference was generally not more than one or two parts. It is possible that while bacterial action was stopped by the sodium chloride, enzyme action was not inhibited.

Magnesia however has one serious disadvantage in that it makes the soil clot on the sides of the tubes so that it is not properly aerated. It is better to use the "alkaline mix" except for very unstable soils such as the glasshouse soil mentioned above.

The shape of the curves is evidently connected with the adsorptive power of the soils. This point is still being investigated and will form the subject of another paper.

#### SUMMARY.

Ammonia can be recovered from soil with an efficiency of 98.5 to 99.5 per cent. in six hours in the apparatus described.

For most purposes it is sufficient to aerate the soil for three hours.

Highly dunged glasshouse soils undergo partial decomposition in the cold with magnesia. In such cases the soil should be aerated with magnesia and strong sodium chloride solution for a definite time, say three hours.

The complete recovery of added ammonia from a calcareous soil is difficult unless the soil is finely ground.

*(Received 30th August 1919.)*

## A NEW METHOD OF TESTING CHEESES.

By ARTHUR GEAKE, M.Sc., A.I.C.

(From the Bio-Chemical Laboratory, Chemical Department,  
University of Bristol.)

It has been shown<sup>1</sup> that an important part of the ripening process of cheeses consists in the proteolysis of the cheese proteins, and it therefore seemed probable that by the estimation of the extent of this proteolysis a knowledge of the degree of ripeness of a cheese might be obtained. Although the ripeness of a cheese is a very important factor commercially, at present purely empirical methods of judgment are in use.

The best methods in use for the estimation of proteolysis are undoubtedly those based on the estimation of amino-nitrogen. The best of these are those of van Slyke<sup>2</sup> and of Sørensen<sup>3</sup>. According to the former method the substance is treated in an aqueous solution with a large excess of nitrous acid and the gases evolved collected in a specially devised burette. After absorption of the nitrous fumes in alkaline permanganate the volume of nitrogen remaining is read off and from this the weight of amino-nitrogen calculated. Many attempts were made to utilise this method but it was finally abandoned for the following reasons:

(1) The apparatus required is somewhat costly and complicated.

(2) Although in the case of amino-acids the method gives accurate results this is not the case with proteins because a small volume of nitrogen is always evolved from the reagents themselves and owing to the small percentage of amino-nitrogen in proteins this correction becomes very great and is moreover uncertain and liable to variation.

(3) In the case of proteins the reaction with nitrous acid must be allowed to proceed for at least half-an-hour, so that if a number of samples are to be tested the method becomes slow.

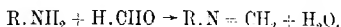
Sørensen's method was found to be suitable for the purpose. The aqueous solution of the protein is brought to neutrality towards phenolphthalein by the addition of standard acid or alkali and is then treated

<sup>1</sup> Compare Nierenstein, this *Journal*, iv, 225 (1912).

<sup>2</sup> B. xliii, 3170 (1910); B. xlix, 1681 (1911); *J. Biol. Chem.* xii, 275 (1912); xvi, 121 (1913).

<sup>3</sup> *Comptes Rendus des Travaux du Laboratoire de Carlsberg*, Vol. vii, Pt. I.

with an excess of neutralised formol. The formaldehyde condenses with the free amino-groups:



and the acid previously combined with them is set free. From the volume of standard alkali required to neutralise this acid the weight of amino-nitrogen is calculated.

Before the amino-nitrogen can be estimated it is necessary to separate the nitrogenous constituents of the cheese from the fat and to bring the former into solution. The fat is most conveniently removed by extracting the fresh cheese sample with acetone. This removes first the water, then the fat and leaves the insoluble nitrogenous residue in a fine state of division. This residue is then dissolved in dilute alkali and measured portions of the solution used for the estimation of amino-nitrogen and of total nitrogen (Kjeldahl). The amino-nitrogen is expressed as a percentage of the total nitrogen and it is this percentage which it is believed may give a measure of the ripeness of a cheese.

The details of the method as finally adopted are as follows:

A sample of the cheese, free from rind, about 8 grams ( $\frac{1}{4}$  oz.) in weight is ground three times in a mortar with portions of 30 c.c. of acetone, the acetone being removed after each grinding by filtration with suction. The last portion of acetone is removed as completely as possible and the pure white nitrogenous residue remaining allowed to dry in the air for a few minutes. About 3 grams of the air-dry residue are roughly weighed out and shaken for an hour in the machine with 50 c.c. of approx. N/10 KOH solution. The greater part is thereby brought into solution. The undissolved residue is filtered off by suction through a thick layer of asbestos; the filtrate should be almost perfectly clear. Usually the filtration is sufficiently rapid but if this is not the case it is frequently convenient to extract the unfiltered liquid once with ether. This removes any fat that may still be present and causes undissolved particles of protein to float on the surface of the aqueous layer. The latter is run off and filters readily. The clear aqueous solution thus obtained is used for the estimation of total nitrogen and of amino-nitrogen.

*Total nitrogen.* 5 c.c. of the solution are digested with 20 c.c. conc.  $H_2SO_4$  and 1 c.c. saturated  $CuSO_4$  solution and the ammonia formed estimated in the usual way by distillation into N/10  $H_2SO_4$ . The excess of sulphuric acid is titrated with N/10 KOH.

*Amino-nitrogen.* A formol solution is prepared by adding 2 c.c. of a 1 per cent. solution of phenol phthalein in 50 per cent. alcohol to

100 c.c. of commercial formol. The solution is titrated with N/10 KOH till just pink. As a control 10 c.c. of this solution are diluted with 20 c.c. of distilled water and titrated to neutrality. The titre should be negligible; if this is not the case the necessary correction is applied to the titres of the cheese solutions.

20 c.c. of the cheese solution are made pink with 0.1 c.c. of 1 per cent. phenol phthalein and titrated to neutrality. This is best carried out by titrating with N/10  $\text{H}_2\text{SO}_4$  till the solution is just colourless and then back-titrating to the neutrality point with N/10 KOH. Great care must be taken not to add more than 0.2-0.3 c.c. excess of  $\text{H}_2\text{SO}_4$ . 10 c.c. of the formol solution are then added and the solution again titrated to neutrality with N/10 KOH. From this last titre (the "formol-titre"), corrected if necessary for the titre of the formol solution itself, the weight of amino-nitrogen in the solution of cheese-protein may be calculated. The amino-nitrogen is however most simply calculated directly as a percentage of the total nitrogen by the expression

$$\text{Amino-nitrogen} = \frac{\text{formol titre}}{\text{ammonia titre (Kjeldahl)}} \times 4 \text{ \% of total nitrogen.}$$

The preliminary experiments were carried out with samples of cheese kindly provided by the Cooperative Wholesale Society of Bristol. The quantities of reagents mentioned above should be strictly adhered to. The addition of more phenol phthalein than given above or of large quantities of salt increases the value obtained for the percentage of amino-nitrogen.

The amino-nitrogen percentage has been measured for a number of samples of cheese kindly sent for the purpose by Miss Jessie Stubbs, N.D.D., Head of the Lancashire County Council Dairy School, to whom I wish to express my indebtedness. In the following table these results are shown in comparison with the grade and general character of the cheese as judged by Miss Stubbs.

Table I.

Date Received	Date Analysed	No.	Amino N		Remarks
			Total N %	Grade	
9/7/14	15/7/14	1	4.79	B	On sour side
"	"	2	5.97	E	New Lane., typical fat
"	"	3	6.98	C	Good quality, strong flavour
"	"	4	4.27	A	Dry, too sour
"	"	5	9.12	F	Old Lane., fat mellow cheese
"	"	6	5.60	D	Cheddar, new
27/8/14	27/8/14	1	4.78	B	On dry side
"	29/8/14	1	4.86		
"	27/8/14	2	6.98	F	Old Lane., fat, strong
"	29/8/14	2	7.32		
"	27/8/14	3	6.72	E	Cheshire, fat
"	29/8/14	3	7.14		
"	27/8/14	4	4.84	D	New Lane., made 8/8/14
"	28/8/14	5	4.97	D	New Lane., made 10/8/14
"	"	6	7.51	E	Cheddar, fat and mild
"	"	7	7.84	F	Cheddar, softer than 6
"	"	8	6.03	E	Cheshire, fat and mild
"	"	9	4.92	A	Too much acid
"	29/8/14	10	7.26	E	Exptl; spongy but fat
"	27/8/14	11	5.70	D	Exptl; more acid, hard
"	29/8/14	11	6.11		

It is regretted that owing to the abrupt conclusion of the work in 1914 it was not possible to test the method more thoroughly.

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# SEED STUDIES: RED CLOVER WITH SPECIAL REFERENCE TO THE COUNTRY OF ORIGIN OF THE SEED

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## INTRODUCTION

THE country of origin of seeds of certain cultivated plants is a question of growing importance, and it is a question which has come into prominence in recent years, owing partly to bad seed harvests at home and to difficulties of transport from abroad. Trials with Red Clover have been conducted on an extensive scale on the Continent. Boerger<sup>(2)</sup> states that experiments made in Germany, Denmark, Sweden, Norway, Holland and Austria prove beyond discussion that Red Clover does not yield its maximum crop unless locally grown seed is used. Roemer<sup>(10)</sup> conducted trials in Germany with Red Clover obtained from eighteen different sources; he states that the best results obtained exceeded the worst by one-third of the crop and that seed harvested in East Germany and Central Germany or in countries east of East Germany are the best for use in East Germany. Trials have not been carried out in England on the same scale as on the Continent. Smith<sup>(12)</sup> at Leeds, however, found that Red Clover obtained from different sources gave very different results for one year leys. He states, for instance, that the greatest weight of hay was obtained from English Single Cut Cowgrass, Canadian, United States and Russian Clovers; whilst amongst those which gave the best stubble grazing in the autumn and spring, after sowing, were Chilian and New Zealand Red Clovers and English Cowgrass, and these were also the clovers which he found stood the winter best. Trials conducted by the writer in Mid-Wales showed that when Chilian Clover succeeded it gave the best stubble grazing; but that at high elevations and on exposed fields it did not stand the winter well. The clovers which stood best into a second year were, moreover, English Single Cut Cowgrass and Red Clovers harvested from the Cotswolds and in Montgomeryshire. Findlay<sup>(8)</sup> has conducted exhaustive trials in the North of Scotland with clovers of different nationalities, and he finds

that seed from England or Wales or from the colder northerly regions (e.g. Norway and Sweden) are more reliable than those from southern warmer climates. Trials have also been conducted by the Trade, and the view is very generally held, rightly or wrongly, that Chilian Clover gives excellent results for ordinary one year leys in parts of Scotland, and the Northern<sup>1</sup> and Eastern Counties of England; but that, generally speaking, good strains of English Clover give the highest yields over the country as a whole, and that for two to three year leys English or Welsh seed is the best and that failing this, of the seed most abundantly on the market that from Brittany and Canada is the most desirable. Piper<sup>(9)</sup> referring to trials conducted in America quotes results obtained at the Wisconsin Experimental Station in 1901, 1902 and 1905, at the Maine Experimental Station in 1902, and co-operatively by the United States Department of Agriculture in 1905. The highest yields were obtained from American (Minnesota, Indiana and Wisconsin) and Orel (Russia) strains. The Orel Clover however yields but one cutting and consequently the total yield for the whole season would probably not be as great as that of some of the American varieties. With regard to the suitability of American Red Clover for Europe, Piper states that it is objected to on account of its greater hairiness, and that the opinion prevails that the yield is not as a rule as satisfactory and that the plants are more subject to mildew.

Such evidence as is available seems then to indicate that the country of origin of Red Clover seed has a direct influence on the resulting crop; the general superiority of English seed, especially of English Single Cut Cowgrass, is moreover suggested by the fact that good strains of English Clover usually fetch a higher price than foreign seed<sup>2</sup>. It is therefore of considerable importance to be able to recognise the country of origin of a clover sample either by inspection or after subjecting the seed to suitable tests. In the past, the contained weed seeds in a sample have been chiefly relied upon in forming an opinion as to "Country of Origin." This method has been used by Saunders<sup>(11)</sup> and Stapledon<sup>(15)</sup> for oat samples, and particulars as to diagnostic weeds met with in samples of grasses and clovers are given by Percival<sup>(8)</sup> and by Parkinson

<sup>1</sup> One reason for Chilian Clover being largely used is, of course, that it is usually cheaper and of better germinating capacity than English; its greater use in Northern Counties being largely due to the fact that the Chilian Dodder is said not to become a serious pest in Scotland and the North.

<sup>2</sup> It is often said that one reason for the higher price of English seed is the fact that it usually contains greater excess of weed seeds than foreign clover, and therefore costs more to clean.



Table I.  
*To show the comparative quality of Red Clovers of different nationalities  
 obtained from the 1916 and 1917 harvests.*

Country of origin	Germination per cent.					Purity per cent. 1917	Remarks as to diagnostic weed seeds
	Highest and lowest for the 2 seasons together				Hard seed per cent.		
	Average 1916 1917	90	90	97-74			
Chile					6 7	98.7	The most characteristic impurity is the Chilean Dodder ( <i>Cuscuta rupestris</i> var.), which was found in 82 per cent. of the samples examined in 1917. <i>Medicago</i> spp. and <i>Brassica</i> spp. are often characteristic impurities, as is Lucerne, which is, however, as or more frequent in Italian and French samples. <i>Rumex</i> spp. and <i>Cruciferae</i> spp. are more abun- dant in Chilean than in other samples. <i>Geranium</i> spp., <i>Danthonia Canadensis</i> , <i>Silene</i> and <i>Lupinus</i> spp. are not frequent in Chilean Clover.
Canada	80	89		97-66	10 7	98.6	The Chilean Dodder is not of in- frequent occurrence in Canadian samples. <i>Rumex</i> , <i>Arctostaphylos</i> is more frequent in Canadian than other samples. <i>Chenopodium</i> spp., <i>Polygonum</i> spp. and <i>Setaria viridis</i> are of general occurrence as are Timothy and Alsike Clover. <i>Ambrosia artemisiifolia</i> is a diagnostic impurity as is <i>Amaranthus</i> spp., although to a lesser degree.

contain a greater number of species of weed seeds than clovers from other nationalities. Ryegrass and Lucerne occur in nearly all samples. *Trifolium repens* and *Echium* are more frequent than in clovers from other countries. *Scirpus viridis* is frequent. *Holcus sp.*, *Anthrobium* spp. and *Valerella* spp. are perhaps the most diagnostic impurities.

The impurities in French samples are somewhat similar to those found in Italian. Birds Foot, Trefoil and *Vicia Echinoides* are usually indicative of Italian origin. *Trifolium repens* and *Trifolium pratense* are plentiful in French samples. *Anthrobium* spp. and *Valerella* spp. are abundant in Italian. *Trifolium repens* is the most striking French impurity occurring as it does considerably more frequently in French than other samples. The absence of *Holcus* spp. and *Anthrobium* spp. and the presence of *Trifolium repens* and *Valerella* spp. are diagnostic of French origin.

British samples are rather characterised by the absence of impurities from Italy. The foreign samples contain a greater number of typical weeds. *Girardinia* spp. are present, however, may almost be regarded as a typical British impurity. Ryegrass and *Valerella* spp. are impurities more generally met with in British clovers although birds foot are sometimes found in Italian and French samples.

The figures for 1916 are based on average results obtained at Aberystwyth. The 1917 data were obtained from the records of the Seed Testing Station.

\* The figures under 1917 for the Italian samples were obtained from tests made on seed of the harvest of 1918.

France	88	87	98-34	3	3	97-0
Britain	75	61	98-1	3	4	96-6

and Smith(7). The "impurity method," however, falls to the ground in the case of well-cleaned samples. The combined result of modern improvements in cleaning machinery and the introduction of the Testing of Seeds Order is, moreover, for cleaner and cleaner samples to be put on the market as time goes on. It was, therefore, decided to start investigations with a view to establishing, if possible, a "country of origin test" other than "impurity" to be applied to Red Clovers.

It is proposed in this article to give an account of the work that has been conducted. It was at first necessary to carry out a number of preliminary tests, and as the enquiry proceeded it was found possible to examine certain phenomena connected with clover seeds in general, but which had no particular relationship to the country of origin of the seed. In order to deal adequately with the subject of this paper it will however be advisable to give a short account of the work as a whole. The major part of the preliminary investigations were conducted by the author at Aberystwyth during 1916 and the beginning of 1917 with samples obtained from the harvests of 1913 to 1916. The work was subsequently continued in greater detail at the Food Production Department's Seed Testing Station with samples obtained from the harvest of 1917.

#### GENERAL CHARACTERS OF CLOVER SEEDS OF DIFFERENT NATIONALITIES

Before describing the detailed investigations which form the subject of this paper, it will serve a useful purpose to indicate the broad differences which occur between the seeds of various nationalities. The comparative qualities of the seeds are shown in Table I.

It will be seen that Chilian and Canadian samples on the average contain the most and French and British the least hard seed. The British samples have a decidedly lower average capacity of germination than the clovers of all the other nationalities considered; Canadian and Chilian samples are consistently better germinators than either British, French or Italian, for, although the average germinations are not markedly higher than that given by the French and Italian clovers, samples with really poor germinations are much less frequently met with. The Chilian and Canadian samples are also superior in the matter of purity and in this respect the British equally with the Italian are the least satisfactory. With regard to specific impurities, the extent to which the large dodder occurs in Chilian samples is to be noted and this, of course, seriously detracts from the otherwise excellent quality of the

seed, although it must be remembered that this particular dodder, even when sown, does not gain a footing in certain districts. The diagnostic features of the contained weed seeds need not be further discussed but will be referred to in the summary at the end of the paper. The above brief review is unfortunately evidence of the fact that on the average the quality of British seed is less good than that of other nationalities. British seed is therefore, generally speaking, of less attractive appearance. Consequently the farmer who purchases seed solely on its appearance or on the basis of a declaration of purity and germination, without regard to country of origin or strain, runs the grave risk of acquiring an article not well suited to his particular needs.

#### DETAILED CONSIDERATION OF THE CHARACTERS OF CLOVER SEEDS OF DIFFERENT NATIONALITIES

Two methods of attack suggested themselves, with a view to recognising the nationality of a sample without having resort to the nature of the weed seeds, namely (1) Careful comparisons of the characters of the seeds, such as size and grain-weight (i.e. weight per 1000 seeds), and the ratio that the seeds of different colours bear to each other in the samples; and (2) The capacity of germination of the samples both at optimum and extreme temperatures, and the germination of the seeds of different colours at different temperatures.

##### 1. THE GRAIN-WEIGHT AND COLOUR CHARACTERISTICS OF THE SEEDS.

The chief results obtained under this heading are set out in Table II.

From five to twenty samples were used for arriving at the figures for each country. The British samples were grouped into six grades according to the quality of the seeds and not less than five samples were used to represent each grade. The seeds were graded into three colour classes only, viz. "Yellow," which included lemon-yellow and slightly yellow-ochre seeds, this group consisted of non-mottled and non-parti-coloured seeds; "Violet," which included violet, mauve, mottled and parti-coloured seeds; and "Brown," which included both well-developed and light brown seeds and also such as were shrivelled and poorly developed<sup>1</sup>. It will be convenient to consider the results of the table firstly from a general point of view and secondly from the point of view of the country of origin of the seed.

<sup>1</sup> This classification differs from that of Franck and Wierigna (5) who separated their samples into Violet, Mottled, Yellow, Brown (well-developed) and Brown (ill-developed). The simpler classification, however, sufficiently served the purpose of the present investigation.

Table II.

*To show the grain-weight of seeds from different countries, and the grain weight of seeds of different colours; also the percentage of yellow and brown seeds in the samples.*

The average germination of the samples which were used for these tests is also shown.

Country of origin		Average germination	Percentage contribution		Weight per 1000 seeds in grms.			
			of yellow seeds	of brown seeds	Violet-cum-mottled	yellow	brown	All colours together*
Chile	1916	90	32.9	4.8	2.26	2.24	2.20	2.25
	1917		33.8	1.5	2.23	2.19	2.14	2.23
Italy	1916	85	29.5	7.8	1.71	1.63	1.49	1.69
	1918		40.1	1.1	1.74	1.68	1.25	1.70
Canada	1916	89	25.5	6.0	1.72	1.54	1.37	1.65
	1917		29.7	5.0	1.69	1.58	1.40	1.62
France	1916	88	19.8	12.8	1.58	1.44	1.28	1.59
	1917		25.4	3.6	—	—	—	1.52
British	1916	94	13.62	15.26	2.00	1.93	1.70	2.02
	1917		12.00	34.00	2.10	1.81	1.70	2.04
"	1916	84	15.35	17.87	—	—	—	2.08
"	1916	76	13.40	25.40	—	—	—	1.94
"	1916	65	9.80	25.80	1.03	1.88	1.58	1.90
"	1916	51	8.30	39.80	—	—	—	1.85
"	1916	31	4.00	31.00	—	—	—	1.73

The greatest weight per 1000 grain of any Chilean sample was 2.52 grms.

The greatest weight per 1000 grain of any British sample was 2.35 grms.

The greatest amount of yellow seed in any British sample was 24 per cent.

The least amount of yellow seed in any Chilean sample was 23 per cent.

\* These weights are the average of a greater number of samples than the weights given for the violet, yellow and brown seeds separately.

#### (a) General.

It will be noted that without a single exception the violet-cum-mottled seeds were heavier than the yellow or the brown, and that the yellow were heavier than the brown. These results confirm those of Franck and Wierigna (5). Birger (1), however, states that yellow and brown seeds do not differ much in weight: this is more or less true in the case of fairly good samples, the brown seed in which is well-developed and not shrivelled, but Franck and Wierigna's figures suggest that even brown seed of this character weighs slightly less than yellow.

A large number of tests were also put up to compare the relative germinations of Yellow, Violet-cum-mottled and Brown seeds. 2200 seeds were used in this connection, the average results were:

Violet-cum-mottled	...	...	85 per cent. germination
Yellow	...	...	84 " "
Brown (largely ill-developed and shrivelled)	...	...	51 " "

Records were also kept as to the amount of "hard" seed given by the different colours both in connection with the above and other tests. The average results were:

Violet-cum-mottled	...	...	7 per cent.
Yellow	...	...	8 "
Brown (normally developed)	...	...	9 "
Brown (shrivelled and ill-developed)	...	...	Less than one per cent.

It will be seen from the above figures that there is little or no difference in the germination of Violet-cum-mottled seeds and Yellow seeds, but that the germination of Brown seeds is not nearly as good: the germination of Brown seeds is, moreover, low in proportion to the amount of shrivelled seed present. Samples varied very much with reference to hard seed, in some cases Violet and in other cases Yellow gave the higher percentage--on the average of several thousand seeds, however, Violet, Yellow and Brown (well-developed) did not differ very much; but Brown (ill-developed and shrivelled) seldom gave rise to hard seed. This fact, as Franck and Wierignac point out, should cause no surprise, for as the result of shrivelling, tension of the seed coat occurs which causes small "bursts" and thereby obviates hardness.

If the average germinations are compared to the grain-weight of the seed, it will be seen that no very definite relationship occurs. For instance, Canadian samples with a grain-weight of 1.6 germinated practically as well as Chilian at 2.2, whilst British samples with an average grain-weight of 2.08 did not give as high a germination as those with a grain-weight of 2.02. British samples with low grain-weights and high percentages of brown seed, however, give low germinations. The grain-weight of a group of British samples germinating 31 per cent. was, however, higher than that of a batch of French samples germinating 88 per cent.

The above facts show that it is only legitimate to make direct comparisons between grain-weight and germination when seed from one and the same sample is used and when shrivelled and poorly developed seed is removed. Separations were made on a number of samples and the "heavy" and "light" seed subsequently germinated. Samples of known origin were used, and care was taken not to work with blended samples, in which case the result of sifting might only have been to segregate the component constituents of the blend. The results of these tests are set out in Table III.

The figures indicate that well-developed "heavy" and well-developed "light" seed drawn from the same sample do not differ materially in

germination<sup>1</sup>. It is interesting to observe, however, that in every case the "light" seed gave rise to a higher percentage of "hard" seed than the "heavy," thus showing that the small and light seed in a sample is more likely to be hard than the larger and heavier seed, and it may be also said that unless "light" seed is shrivelled or undeveloped it will germinate as well as the heavy seed<sup>2</sup>.

Table III.

*To show the relative germination capacities of "heavy" and "light" seed separated from the same samples after removing all the ill-developed and shrivelled seed.*

Origin of samples	Weight per 1000 grain	Germination per cent.	Hard Seed per cent.
England	2.40	86	13.0
	1.75	84	16.0
France	2.05	96	1.4
	1.51	96	1.0
Chile	2.40	94	5.0
	1.79	91	8.0
Canada	2.10	93	4.8
	1.64	93	7.0
Canada	2.10	91	8.0
	1.57	90	10.0

Average results:

Grain over 2 grs. per 1000, germination 92 per cent., hard seed 6.4 per cent.

Grain less than 2 grs. per 1000, germination 91 per cent., hard seed 9.0 per cent.

<sup>1</sup> Tests of a similar nature had been previously conducted on Oat samples and the results obtained were precisely the same, in some cases the smaller lighter seeds germinated considerably faster than the larger heavy seeds. In the case of Oats, however, the light poorly developed "pinched" seed frequently gave a high percentage of germination.

<sup>2</sup> In connection with what has been said above as to the relationship between grain-weight and germination it is of interest to refer to Findlay's (4) work on the size of seed in relation to crop production. He states in summing up his evidence, "That there is no connection between the size of seeds and the produce. True, the largest seeds—the Late Flowering—undoubtedly produce the heaviest crop the first year, but the Broad Leaved English—the smallest seeds—produced the next heaviest. In the second and third years and also on the aggregate the Norwegian—the second smallest seed—produced the heaviest crop, while the Hungarian and medium sized seed gave by far the poorest crop every year." With reference to seeds of different size taken from the same sample, Findlay makes the following observations, "Undoubtedly in many, if not most of our farm seeds, there is a mixture of strains," and in the case of some of his trials it appeared as if the smaller seed represented better and more lasting strains than the large seed.

(b) *The Country of Origin of the Seed*<sup>1</sup>.

The figures in Table II show some interesting differences between the samples representing different countries. It will be noted that the Chilean samples have the highest grain-weight and that English samples come next in weight, but that the heaviest individual English sample was only slightly heavier than the average of all the Chilean samples.

Samples from Canada and Italy have very similar grain-weights, whilst those from France are the lightest.

The relative amount of yellow and brown seed in the samples in conjunction with the grain-weight of the sample as a whole, however, affords the best guide as to country of origin. The *Chilean* seeds are remarkable for having a high percentage of yellow seed and an insignificant amount of brown, and consequently, although of very similar grain-weight to some of the best English samples, are generally easily distinguished. The grain-weight of such brown seed as is found in Chilean samples is, moreover, much closer to that of the yellow and violet-cum-mottled seeds than in the case of other nationalities. Seed from *Canada* cannot be readily distinguished from that from *Italy*, for the grain-weights and proportions of yellow and brown seeds are very similar although, on the average of two years, the Italian samples would appear to contain the higher proportion of yellow seeds. The seeds of these nationalities, however, differ from Chilean and British in respect of a lower grain-weight, from Chilean on account of a slightly lower proportion of yellow seeds, and from British on account of a considerably lower proportion of brown seeds. The French seed, like the British, would seem to vary more from year to year than that from Chile, Italy and Canada; the low grain-weight appears to be the most constant characteristic. The high proportion of brown seed is the outstanding feature of British samples, and this would seem to differentiate it from the other nationalities considered.

Since the weight of the seed of different nationalities varied and since it was obvious that the difference in weight was correlated with a difference in size, it seemed advisable to conduct experiments with a view to examining the applicability of a "size test." A number of samples were therefore divided into two grades by passing the seed over

<sup>1</sup> It was not found possible during the War to procure a sufficient number of samples for the purposes of this investigation from countries other than those recorded in the Table.



a 1.5 mm. sieve<sup>1</sup>. Tests were subsequently conducted on the two sizes of seeds separately. The results of the sieving tests are given in Table IV.

Table IV.

*To show the proportion of seeds retained in and passed by a 1.5 mm. sieve in the case of samples of different nationalities.*

1.5 mm. sieve	Percentages by weight of seed.				
	Chilian	British (1)	British (2)	Canadian	French Italian
Seeds retained	73.4	66.6	55	20.6	18 20
Seeds passed	26.6	33.4	45	79.4	82 80

It will be seen from the above figures that the simple process of sieving (a quicker method than ascertaining grain weights) serves readily to differentiate between British and Chilian samples on the one hand and Canadian, French and Italian on the other.

A sample containing a fair proportion of brown seed was selected from (a) the Canadian samples, (b) the French and (c) the British. Each sample was graded by passing over a 1.5 mm. sieve and the brown and shrivelled seed was then separated from the well-formed and bright seed. The results are shown in Table V.

Table V.

*To show the proportion of bright and well-formed and of dull (brown) and ill-formed seeds retained and passed by a 1.5 mm. sieve in the case of samples of different nationalities.*

1.5 mm. sieve	Percentages by weight of seed.			
	Character of seed	Canadian	French	British
Seeds retained	Well-formed	23.1	32.0	53.0
	Brown and shrivelled	2.3	1.5	11.0
Seeds passed	Well-formed	68.3	62.3	27.0
	Brown and shrivelled	6.3	4.2	9.0

It will be seen in the case of both the Canadian and French samples that the greater amount of ill-developed seed was amongst the smaller seed, whilst the ill-developed seed was more or less equally distributed between the large and small seed in the British sample.

It has been previously shown that large and small seed taken from a uniform non-blended sample do not differ materially in germination. It seemed probable, however, that sieving a blended sample would be likely to more or less separate the seeds into their component bulks,

<sup>1</sup> It was not possible to obtain an absolutely accurate sieve, with a uniform perforation. The same sieve was of course used for all the tests.

Table VI.

*To show the proportion of seeds retained and passed by a 1.5 mm. sieve,  
and the germination of the large and small seed in the case of samples  
which consisted of a blend of seeds of two nationalities.*

		A—large seed.		B—small seed.		
(This Table should be considered in conjunction with Table IV.)						
Provenience	Nationalities	Proportions of seed		Percentage germination		Remarks as to interpretation of the results
		A	B	A	B	
83	English and French	67	33	42	37	Might have been wholly English, the French seed probably did not germinate as well as the English
141	"	65	35	38	33	ditto
426	"	17	83	55	70	The great majority of the seed was probably French.
427	"	19	81	22	47	ditto
569	"	34	66	33	62	A considerable admixture of French seed with a higher germination than the English
598	"	34	66	84	85	A considerable admixture of French seed with a germination about the same as the English
614	"	36	64	78	88	A considerable admixture of French seed with a germination higher than the English
737	"	10	90	59	76	The great majority of the seed was probably French with a germination higher than the English
781	"	47	53	16	19	A slight admixture of French seed with a germination but slightly higher than the English
915	"	38	62	47	60	A moderate admixture of French seed with a germination decidedly higher than the English
945	"	56	44	77	79	Nothing to show that the sample was not wholly English
1007	"	14	86	62	78	The great majority of the seed was probably French
1185	"	44	56	27	55	A slight admixture of French seed with a germination decidedly higher than the English
1194	"	47	53	13	21	ditto
94	English and Chilian	56	44	58	65	The differences in germination suggest a blend, but would not have implied Chilian and English
114	"	46	54	77	71	The proportions suggest a blend, but would have implied an admixture with Canadian or French seed rather than Chilian
698	"	28	72	72	40	The figures would rather have suggested an admixture of a little Chilian with a large amount of poor French or Canadian
556	French and Chilian	28	72	50	60	The figures suggest a blend and although not incompatible with a poor Chilian and French seed would have suggested English and French
295	English and Canadian	38	62	59	69	A moderate admixture of Canadian seed with a better germination than the English
992	English, French, Canadian	23	77	79	93	A considerable admixture of Canadian and French seed with a decidedly higher germination than the English

and that this would especially be so in the case of blends consisting of large seeds such as British or Chilian with small seeds such as Canadian and French. Thus, if a sample was separated into two sizes and the germination given by the two grades was decidedly different, it would appear reasonable to suppose that such a sample was a blend; if the germinations were practically the same, this would not of course, preclude the possibility of the sample having been blended. Further, if the smaller seeds germinated much better than the larger, this would suggest that French, Italian or Canadian stocks (which usually give higher germinations than British) had been blended with British seed. The comparative germinations of seeds retained and passed by a 1.5 mm. sieve would not, however, be likely to lead to the recognition of country of origin in a mixture of seeds of nearly equal size such as Canadian and French or of Chilian and British. A consideration of the proportions of seed both passed and retained by a 1.5 mm. sieve (having regard to the proportions that may be expected for samples representing different nationalities) in conjunction with the germination capacities of the siftings might reasonably be expected, however, to help to decide whether a sample was a blend of different nationalities. In order to ascertain whether trials conducted on these lines would be likely to be informing, a number of samples sent to the Seed Testing Station as blends of stated nationalities were tested. The results are given in Table VI.

The facts set out in Table VI and the interpretation put upon the figures show that with but three or four exceptions the tests applied to the samples in question although not being sufficient to give exact, or in some cases even approximate, evidence as to what precise nationalities were involved, none the less would have led to the assumption that the samples were blends.

In order, further, to examine the usefulness of the combined sieving-germination test, it was applied to a number of samples which were sent to the Station "as English" but which owing to their appearance and the contained weed seeds aroused suspicion. The results of these tests are set out in Table VII.

It will be noted that with a single exception (Aa 1241) the sieving-germination test tended to confirm the evidence afforded by the presence, in mere traces, of diagnostic weed seeds. The ratio of large to small seed was furthermore, more or less what would have been expected from an admixture of English with French or Canadian seed. The combined evidence of the weed seeds and sieving-germination tests amount to almost positive proof that the samples under review did not consist wholly of English seed.

Table VII.

To show the proportion of seeds retained and passed by 1.5 mm. sieve and the germination of the large and small seed in the case of a number of samples sent to the Station as "English" but which contained impurities diagnostic of foreign origin.

A = large seed.

B = small seed.

(This Table should be considered in conjunction with Tables IV and VI.)

Reference	Contained weed seeds suggestive of the foreign origin of a part at least of the sample	Proportions of seed		Percentage germination		Remarks as to the interpretation of the results
		A	B	A	B	
a 11	<i>Setaria</i> sp. and <i>Amaranthus</i> sp. (suggests Canadian origin)	47	53	38	40	Suggests that French, Canadian or Italian seed of about equal germination to the English bulk was added. The weed seeds indicate that the admixture consisted of Canadian seed
aa 107	<i>Verbena</i> sp. (suggests French origin)	6	94	72	70	Suggests that the sample consisted almost entirely of one of the small-seeded nationalities—the presence of <i>Verbena</i> indicating that the seed was French
Aa 461	<i>Centaurea Maculosa</i> (suggests French origin)	33	67	54	72	The figures suggest that a small-seeded nationality of considerably higher germination than the English seed was added in moderate amount. The contained weed seed implies French origin
Aa 731	<i>Setaria</i> and <i>Lucerne</i> (suggests French or possibly Chilean origin)	30	70	41	53	The figures again indicate the admixture of a small seeded nationality of better germination than the English seed, the adulterant was therefore probably French seed
Aa 846	<i>Setaria</i> and <i>Centaurea maculosa</i> (suggests French origin)	40	60	37	45	A slight admixture of French with the English seed is suggested by the weed seeds and is borne out by the figures
Aa 1090	<i>Ambrosia Artemisiifolia</i> and Chilean dodder* (suggest Canadian origin)	39	61	73	82	The figures support the view that a Canadian seed of higher germination than the English was used to reinforce the bulk
Aa 1241	<i>Lucerne</i> , <i>Lepidium campestre</i> and <i>Daucus Carota</i> (suggests French and Canadian origin)	50	50	90	90	The figures do not necessarily imply a blend and are not incompatible with English seed
Aa 1145	Birds Foot, Trefoil, <i>Lucerne</i> , <i>Brassica</i> spp., Chilean and English Dodder (suggests Chilean and French origin)	8	92	18	21	The figures suggest that the sample consisted for the most part of one of the smaller seeded nationalities, the impurities indicating French seed. The presence of Chilean dodder and <i>Brassica</i> , however, implies a slight admixture with Chilean seed also

\* Chilean dodder has been frequently found in Canadian samples, consequently it does not follow that Chilean clover was necessarily used as an adulterant in this case.

The very small amounts of heavy seed in Aa 757 and Aa 1007 (Table VI) and in Aa 1145 (Table VII) suggest that the majority of these samples consisted of siftings or cleanings. It has, therefore, to be borne in mind, in this connection, that a blend of large and small seed of the same nationality could not be distinguished from a blend of different nationalities by the sieving-germination test alone.

The data brought forward in this section show, however, that by an adroit use of the grain-weight, colour ratio, and sieving-germination tests, it is possible to form some opinion as to the country of origin of a sample and in certain cases as to the component nationalities of a blend.

It will be shown hereafter that differential germination tests afford further evidence, and in the summary at the end of the paper an endeavour will be made to indicate a scheme of testing that will help towards the recognition of blended samples as such and the nationality of the clovers so blended.

## II. GERMINATION TESTS CONDUCTED AT OPTIMUM AND EXTREME TEMPERATURES.

It will be convenient to deal with the work carried out in this connection under two sub-headings as before, *i.e.* (a) *General*, and (b) *As it bears upon the country of origin of the seed.*

### (a) *General.*

It seemed probable that germination tests conducted at different temperatures might reveal facts concerning the quality of seeds not shown by tests conducted at optimum temperatures, also that the rapidity of germination at different temperatures might prove of significance, and that the results so obtained might be influenced by the country of origin of the seeds.

Nearly 200 samples of seeds were used in conducting the necessary tests and over 1200 germination tests (3-6 sets of 100 seeds each) were made. The seeds were germinated in closed Hearson Incubators at 20° C., 25° C., 30° C., 35° C. and 40° C. At Aberystwyth the sets were put up in petri dishes, with a seed bed of two moist filter papers and covered with a single moist paper<sup>1</sup>. The moisture was kept as uniform as possible (*e.g.* about 60 per cent. saturation) throughout the test by spraying as necessary. At the Seed Testing Station, the sets were put up on glass

<sup>1</sup> 4 in. petri dishes were used and an initial uniformity of moisture was assured by using 5 c.c. of water per each petri in the first instance

Table VIII.

*To show average germinations of samples of different grades and ages at different temperatures; the top figures are the actual germinations and the bottom figures the percentage loss of germination below that at 20° C.*

*Samples tested from current (1916) harvest.*

Character of samples	20° C.	25° C.	30° C.	35° C.	40° C.
Grade 1	87	87	84	77	60
97 samples		0	3.4	11.4	31.0
Grade 2	73	68	62	58	22
30 samples		6.8	15.0	20.5	70.0
Grade 3	46	43	31	30	9
15 samples		6.6	32.6	34.8	80.4
Grade 4	31	26	21	16	2
3 samples		16.0	32.2	48.3	93.5

*Samples of different ages.*

(a) Yearling = 1 year old.

13 samples	75	75	75	57	35
Original germination	(Loss 18.4 % as a result of keeping one year)	0	0	24.0	53.3
92 %					

(b) Two years old.

2 samples	76	74	76	67	26
Original germination	(Loss 21.6 % as a result of keeping two years)	2.6	0	11.8	65.8
97 %					

(c) Three years old.

6 samples	48	40	21	16	3
Original germination	(Loss 48.0 % as a result of keeping three years)	8.5	56.2	66.6	93.7
94 %					

(d) Four years old.

15 samples	26	16	10	7	3
Original germination	(Loss 72.9 % as a result of keeping four years)	38.4	61.5	73.0	88.4
96 %					
10 samples	8	4	4	2	0
Original germination	(Loss 88.0 % as a result of keeping four years)	50.0	50.0	75.0	100
66 %					

(e) Five years old.

1 sample	8	1	5	0	0
Original germination	(Loss 91.7 % as a result of keeping five years)	87.5	37.5	100	100
97 %					

plates standing on petri dishes containing water, the filter papers on the glass plates being kept moist by wicks. This latter proved much the best plan for the purpose required since uniformity of moisture in all cases was assured.

The preliminary germination tests were conducted wholly at Aberystwyth with seeds of obviously different qualities. Samples of different ages, which had accumulated in the writer's laboratory at Aberystwyth, and those representing different grades of the 1916 harvest were first tested at different temperatures, no regard being paid to the country of origin of the seeds. The average results of these preliminary tests are set out in Tables VIII and IX.

Table IX.

*To show the percentage number of samples of grades 1, 2 and 3 (see Table VIII) which germinated best at the several temperatures.*

Character of samples	Germination at				
	20° C.	25° C.	30° C.	35° C.	40° C.
Grade 1 Average germination at 20° C. = 87%	53%	25%	12%	4% germinated as well as at lower temperatures	None germinated as well as at lower temperatures
Grade 2 Average germination at 20° C. = 73%	66%	23%	2%	None	ditto
Grade 3 Average germination at 20° C. = 46%	55%	20%	0.5%	None	ditto

The figures show that the better quality samples resist the higher temperatures much better than the inferior grades. In the case of all grades, however, the average figures show a considerable falling off at 35° C. and a greater falling off still at 40° C. Inferior samples frequently, however, are unable to resist 35° C. and (or) even 30° C. as well as good samples can 40° C. When individual samples are considered and not average figures (*vide* Table IX) it will be seen that the optimum temperature for germination of Red Clovers cannot be expressed as a single temperature but varies for individual samples from a temperature probably about 20° to as high as 30° C., but that the majority of samples may be expected to germinate best at a little above 20° C. Thus the usual temperature employed for testing clovers, *i.e.* 22° C., is probably the best single and uniform temperature to use as favouring the majority of the samples tested, but will by no means give the best results for an appreciable proportion of the samples.

In the case of really good samples the difference between the germinations obtained at 20° C., 25° C. or even 30° C. seldom amounts to more than 5 per cent. In the case of poor samples, however, the difference between the results obtained at 20° C. and 25° C. may in a few instances amount to 10 or 12 per cent. and although the higher figure in the case of these big discrepancies is generally obtained at 20° C., in about 12 per cent. of such cases it occurred at 25° C.

If grades 3 and 4 (from a current harvest, see Table VIII) are compared respectively with samples three and four years old having very similar germinations, it will be noted that the old seeds show a greater falling off in germination at 25° C., and a very much greater falling off at 30° C. and 35° C. than do the seeds from a current harvest whose poor germination must have been due solely to adverse conditions at harvesting<sup>1</sup>. A comparison of the results obtained for yearling and two year old samples with grade 2 samples from a current harvest of about similar germination, if anything, show in favour of the older samples. It would thus seem that if originally good samples are well stored very pronounced deterioration need not take place until the third year and that the behaviour of samples at 30° C. and 35° C. in comparison with their germinations at 20° C. affords some indication as to whether inferior germination is due to a sample being three or more years old or to the fact that the seed matured and (or) was harvested under adverse conditions.

It is evident from the above consideration of the facts that the behaviour of a sample at temperatures above the optimum has a definite bearing on the quality of the seed. It may be of interest, therefore, to compare the energy of germination of a few samples with their germinations at different temperatures. Ten samples were grouped in pairs, each pair having practically similar germinations, in some cases the energy was also similar, in others it was decidedly different. The results of the tests are given in Table X.

It will be seen that in groups (3), (4) and (5) where the energy of germination was higher in one sample than the other, the degree of resistance to higher temperatures was greater in the case of the sample with the best energy of germination. In groups (1) and (2) where the energy was practically the same in the case of both samples in each group, the resistance to high temperatures was much greater in G 16 than G 11 and in F 16 than F 10. It would therefore appear that

<sup>1</sup> The loss of germination at 40° C. is so great in the case of both old and poorly harvested seed that a comparison of results at this temperature is without significance.



germination tests conducted at extreme temperatures would afford a more certain index of vigour than the energy of germination at optimum temperatures<sup>1</sup>. It will be shown in the next section, however, that the results of energy and differential temperature tests are open to mis-interpretation and should only be used as a guide to excellence when comparing samples of the same strain and from the same country of origin<sup>2</sup>.

Table X.

*To contrast the energy of germination of samples with their behaviour at different temperatures.*

Samples	Energy of germination (=3 days at 20° C.)	Germination at				
		20° C.	25° C.	30° C.	35° C.	40° C.
(1) G 16	71	82	75	75	75	55
G 11	71	82	80	71	60	11
(2) F 16	54	79	82	71	68	53
F 10	57	78	78	63	50	22
(3) G 43	41	55	53	46	40	20
G 18	22	56	48	24	29	20
(4) E 2	45	54	61	54	48	28
B 1	36	55	53	50	52	10
(5) B 2	40	50	50	50	48	10
D 3	21	50	40	26	23	2

It will be convenient to consider the question of hard seed and the behaviour of seeds of different colours at different temperatures in conjunction with the nationality tests described in the next section.

*(b) The Country of Origin of the Seed.*

WITHOUT REFERENCE TO THE COLOUR OF THE SEED OR TO HARD SEED.

Samples representing the various nationalities were tested at different temperatures; the average results are set out in Table XI.

It will be noted that the germinations reached in 20 hours were in all cases less when tested by the method adopted at the Seed Testing Station (*i.e.* on filter papers kept moist by wicks) than when tested under drier conditions on moist filter papers not served by wicks<sup>3</sup>.

<sup>1</sup> That resistance to high temperatures affords an index of vigour is, of course, implied by the results given in Table VIII.

<sup>2</sup> It was intended to grow a number of the samples tested in nursery lines in order to compare growth with the germination tests here described. Owing to the writer leaving Aberystwyth early in 1917 it was unfortunately impossible to do so.

<sup>3</sup> Tests at the Seed Testing Station have proved that the "wick" method tends to maintain too wet a seed-bed for red clovers especially in the case of samples of poor quality; these seeds are now tested on filter papers resting upon moist sand.

Table XI.

*To show the germination of samples representing different nationalities at different temperatures. The upper figures are the Aberystwyth (1916 harvest) results and the lower the Seed Testing Station (1917 harvest) results. The figures in brackets represent the percentage decrease in germination below that given in 10 days at 20° C.*

The figures directly below each nationality indicate the number of samples upon which the Aberystwyth averages were based. The Seed Testing Station results were obtained on bulks made up of a large number of samples.

Country of origin	Percentage germination at									
	20° C.		25° C.		30° C.		35° C.		40° C.	
	in 20 hrs.	in 240 hrs.	in 20 hrs.	in 240 hrs.	in 20 hrs.	in 240 hrs.	in 20 hrs.	in 240 hrs.	in 20 hrs.	in 240 hrs.
Chile (30)	70	90	80	90	81	91	68	87	36	71
							(3.3)		(21.1)	
	3	95	12	95	61	95	12	89	20	73
							(6.3)		(23.0)	
Italy* (9)	66	85	69	86	70	82	55	72	33	54
						(3.5)	(15.5)		(36.4)	
Canada (12)	36	89	42	86	42	83	40	77	20	64
				(3.3)		(7.0)	(13.3)		(28.0)	
	8	89	4	91	7	88	1	63	12	73
						(1.1)	(29.41)		(18.0)	
France (6)	64	88	78	88	76	88	63	89	13	60
							(2.2)		(31.7)	
	5	93	46	95	59	94	7	90	11	72
							(3.2)		(22.5)	
Britain† (46)	27	86	52	84	43	77	30	71	9	50
				(2.3)		(10.1)	(17.4)		(41.8)	
	3	80	20	80	23	81	3	63	0	41
							(21.2)		(61.2)	

\* An insufficient number of Italian samples were received at the Seed Testing Station in the season 1917-18 to conduct these tests.

† Only the results obtained on good British samples are included in this Table, in order to compare germinations as near as possible to those of the foreign clovers.

The final germinations obtained by the two methods are, however, seen to be sufficiently comparable. In some respects the seeds of all nationalities behave in a similar manner, for instance the rate of germination with but one minor exception was greater at 25° C. than at 20° C., and no very appreciable difference was to be seen between the rates at 25° C. and 30° C. At 35° C., however, germination began to be much slower even in the case of samples which reached nearly as high final figures as at 20° C. or 25° C. It will be noted also, that the final germina-

tions at 35° C. were lower than those at 30° C. and that with but one exception (Canada) the final results at 40° C. were very considerably lower than those at 35° C. (cf. Table VIII). The irregular behaviour given by the Canadian sample tested at the Seed Testing Station must, almost certainly, have been due to an error or an accident; the temperature of the 40° C. incubator may have dropped or that of the 35° C. incubator advanced during some period of the test. The results given in the Table show very marked contrasts between the British and foreign samples. Speaking generally, the foreign samples germinated faster than the British at all temperatures, but 25° C. gave the least well marked contrast in this respect. The final germinations at 35° C. showed a greater proportional falling off in the case of the British than all other samples (except the Canada result which is suspect) whilst at 40° C. the proportional drop was even greater, being on the average over twice as considerable for the British as the Chilean samples.

The figures show that the behaviour of the different foreign samples under review is not sufficiently varied to distinguish one nationality from another by the results given at different temperatures. It would seem, however, that the Chilean samples tend to be the fastest germinators at all temperatures and tend also on the average of seasons to do proportionately better at 40° C. than the French, Canadian or Italian samples. It is unfortunate that the relatively small seeded Canadian, Italian and French samples cannot be differentiated by resort to the tests described; it would, however, appear as if the French and Canadian seed withstand high incubation temperatures rather better than the Italian.

Although the results can clearly not be used to identify the actual nationality of any particular sample, they are of decided interest and undoubtedly afford a useful addition to methods previously discussed to aid in differentiating between home grown and foreign clovers. In particular the contrast between the behaviour of Chilean and British samples is so great as to have very considerable practical application.

It may therefore be interesting to give some further comparative details relative to the tests conducted on these samples. A comparison of the number of British and Chilean samples germinating best at the different temperatures is made in Table XII and the average rates of germination of six typical Chilean samples and eight typical British samples are shown in detail in Table XIII.

The tables are self-explanatory and do not demand comment. It is, however, of special interest to note that Chilean clovers may begin to

germinate at 30° C. (if the seed bed is not too wet) after no more than eight hours, and will practically complete their germination in three days, and have an exceedingly high energy of germination (i.e. germination in three days) at 20° C. A high rapidity of germination (i.e. germination in 20 hours) with a high energy of germination would always be sufficient to render a "British" sample suspect, thus it is unfortunate that emphasis is often laid on the value of the "energy" test without any reservations being made in the direction of explaining that the energy of germination of British samples is usually low compared to foreign.

Table XII.

*To show the percentage number of Chilean and British samples (Aberystwyth results) which germinated best at the different temperatures.*

Nationality	At 20° C.	At 25° C.	At 30° C.	At 35° C.	At 40° C.
Chile	30	27	27	None best but 27 as well as at lower temperatures	None
Britain	87 best or equally as good	15	2 14 did equally well	None best but 5 as well as at lower temperatures	None

Table XIII.

*To compare the rapidity, energy and final germinations of typical Chilean and British Clovers at certain temperatures.*

Nationality	At 20° C.				At 30° C.					At 40° C.		
	12 hrs.	20 hrs.	3 days	10 days	8 hrs.	12 hrs.	20 hrs.	3 days	10 days	12 hrs.	20 hrs.	10 days
Chile	32	70	88	92	5	60	81	91	93	11	40	72
Britain	8	53	75	86	0	32	53	73	77	0	9	50

The results given in Tables XI and XII suggest that it would not be necessary to put up germination tests at 20° C., 25° C., 30° C., 35° C. and 40° C. on any sample that was suspect. The best plan to follow in the case of samples giving a high rapidity of germination at 20° C. would be to put up an additional test at 35° C. taking care not to have a sodden seed bed and let this additional test run for 20 hours. If something like 50-60 per cent. of the seeds germinating in 10 days at 20° C. germinated in 20 hours at 35° C. this would render the sample in question more than ever suspect and exhaustive tests on the lines suggested in the summary should then be undertaken.

It was pointed out in an earlier section that by separating a sample into seeds of two sizes and germinating the seeds separately, it was possible to obtain an indication as to whether a sample was a blend. It would now appear that if the seeds in one separation although of equal germinating capacity to those in the other were more resistant to incubation at higher temperatures, this would afford additional evidence.

A number of tests were therefore conducted on large and small seeds extracted from single unblended samples, and these were germinated separately at 20° C. and 40° C.; it was found in many instances that large and small seeds as such did not behave differently at the two temperatures but that on the average the small seed appeared to be slightly more resistant to incubation at 40° C. than the large, differences in excess of 5 per cent. were, however, the exception.

Thus when differences of the order of 8 to 10 per cent. in the power of resistance to incubation at 40° C. are met with, the implication is that foreign seed has been used in the blend. If reference is made to Table VI giving the results of the combined sieving-germination test it will be noted that Aa 83, Aa 141 and Aa 945 were designated blends of English and French, but that the sieving-germination test would not alone have been sufficient to recognise this fact, a comparison of the germinating capacities at 20° C. and 40° C., however, affords the necessary clue, for the smaller (presumably chiefly French) seed proved to be 8 per cent. more resistant at 40° C. than the larger in the case of Aa 83; 11 per cent. in the case of Aa 141 and 20 per cent. in the case of Aa 945; and this notwithstanding the fact that the germination of both large and small seed were practically the same at 20° C. It is only necessary to add that in 18 cases out of 28 tested by both the sieving-germination method and at 20° C. and 40° C. a comparison of the results at the higher and lower temperature tended to further confirm the fact that the samples were, as stated, blends of English with either French or Canadian seed. It is not so easy to identify blends of English and Chilian clover by the sieving method and subsequent germination of the separations at 20° C. and 40° C. because the seeds on both sides of the sieve are frequently too similar to the original blend. It is also difficult to detect the component nationalities of a blend in the case of many yearling or older samples when the germination of all the seed is low and the power of resistance of all the seed to incubation at 35° C. and 40° C. is also poor.

## WITH REFERENCE TO THE COLOUR OF THE SEED.

The average results obtained in respect of the seeds of different colours at different temperatures for the various nationalities are given in Table XIV.

Table XIV.

*To show the germination of the seeds of different colours at different temperatures for various nationalities.*

Nationality	Yellow at			Violet-cum-mottled at			Brown at		
	20° C.	30° C.	40° C.	20° C.	30° C.	40° C.	20° C.	30° C.	40° C.
Chilian	88	92	76	83	85	64	70	60	3
British	81	80	48	83	76	38	(a) 39	39	7
							(b) 12	14	1
French	82	81	73	88	91	41	72	60	5
Canadian	77	74	50	84	91	65			
Italian	85	72	54	92	87	65			
Average figures	84	82	63	85	84	55			

(a) More or less well formed brown seeds.

(b) Shrivelled and ill-developed brown seeds.

It will be seen that with the exception of the Italian (where the violet were slightly more resistant than the yellow) the yellow seeds are a little more resistant to incubation at 40° C. than are the violet-cum-mottled. Individual samples of all nationalities, however, give violet seeds more resistant than yellow, so that it is probable that the nationality of the seed does not influence the comparative resistance as between yellow and violet seeds, but that on the average, yellow seed is slightly more resistant than violet. This is what might be expected in view of the fact that speaking generally it is those nationalities which contain the most yellow seed that give the highest germinations at 40° C. The figures in the table show that brown seed of all nationalities is far less resistant to incubation at 40° C. than yellow or violet, and that ill-formed and shrivelled brown seed is hardly capable of germination at 40° C. The poor germination of British samples at 10° C. is therefore largely due to the considerable amounts of brown seed they usually contain. That the poor resistance of the brown seed is not alone sufficient to account for the difference between British and foreign samples is, however, evident from consideration of the figures in the table, for yellow and violet British seeds are seen to be less resistant than yellow and violet Chilian, French or Canadian seeds.

## WITH REFERENCE TO HARD SEED.

The amount of hard seed in samples did not on the average vary very much when the seed was incubated at different constant temperatures, but in most samples tended to be rather less at 40° C. and in some cases less at 35° C. than at lower temperatures. The results obtained on selected samples containing high percentages of hard seed are set out in Table XV.

Table XV.

*To show the effect of Incubation at different constant temperatures on the amount of hard seed.*

		Percentage of hard seed.				
Reference		At 20° C.	At 25° C.	At 30° C.	At 35° C.	At 40° C.
Canadian	J 2	22	25	27	25	16
	J 6	14	7	10	8	—
	J 9	21	16	24	15	—
	J 10	11	12	12	10	—
Italian	K 6	14	27	12	15	—
Chilian	A 8	12	12	11	14	15
	A 12	—	14	9	6	10
	A 26	11	2	7	6	1
English	D 2	42	42	—	33	20

It will be noted that the greatest decrease occurred in the case of the English sample D 2 which contained only half as much hard seed when incubated at 40° C. as at 20° C. It would appear, therefore, that hardness is a matter of degree and that much of the hard seed in D 2 was not as "hard" as that contained in the Chilian sample A 8, for example. That hardness is a matter of degree is further shown by the fact that "hard" seed when incubated for long periods will continue to germinate slowly. The hard seed was collected from a number of Chilian samples after the ordinary test of 10 days at 20° C. and incubated for a further 18 days at different temperatures with the following results:

At 22° C. gave 15 per cent. germination and 86 per cent. hard.

25° C.	"	16	"	"	"	84	"	"
35° C.	"	32	"	"	"	65	"	"
40° C.	"	44	"	"	"	53	"	"

The above figures go to show that temperatures at and above 35° C. are less favourable to hardness than lower temperatures and tend to confirm Harrington's (c) view that the selection of any particular constant temperature from 1° C. to 30° C. has little effect upon the softening of impermeable clover seeds.

There was no evidence to show that hard seed from clovers of different nationalities behaved very differently at different temperatures, or that hard yellow, violet-cum-mottled or brown seed behaved in any way differently the one from the other at different temperatures. Consequently the behaviour of hard seed is of little or no diagnostic significance in relation to nationality tests. A number of tests were conducted to ascertain whether a fluctuating temperature between 20° C. and 10° C. would obviate hardness, and it was found that no very appreciable results were obtained. This confirmed Harrington's (6) experiments, for he found that alternations of temperature have but little effect if none of the temperatures used fall below 20° C. He found, however, when a temperature of 10° C. or cooler is used in alternation with a temperature of 20° C. or warmer that many hard seeds germinate and that the effect of such an alternation of temperature is greatly increased by previously exposing the seeds to germination conditions at a temperature of 10° C. or cooler<sup>1</sup>.

#### SUMMARY AND CONCLUSIONS.

(1) Current literature has been cited to support the view that the country of origin of Red Clover has a very important bearing on the suitability of the seed for crop production in any particular locality; it is therefore a matter that should be considered of just as much and

<sup>1</sup> It is of interest to give a brief account of Harrington's conclusions relative to the use of "hard" (=impermeable) seeds. The value to the farmer of hard seed will vary according to the kind of seed, the germinating capacity, the percentage of hard seed, the age (in samples several years old the "hard" seed may be of more value than the rest of the bulk) and time of sowing of the seed. If the amount of hard seed is not considerable, say less than 10 per cent., and if the rest of the "lot" consists of strong germinable seed the "hard" seeds are of little importance, both because of their fewness compared to the seeds that will germinate readily and because of the varying sowings per acre according to common practice. "Hard" clover seed sowed early in the spring is of more value than the same seed sown later; when sown early in the spring a month or so before the end of freezing weather, the chances are that the majority of the hard seed will germinate; when sown after the freezing period but a month or so before the end of the cool weather about two-thirds of the seed may be expected to germinate, but when sown late in the spring or in the summer probably only about one-tenth of the hard seed will germinate.

It may be added that in this country (Harrington's investigations were conducted in America) clovers are usually sown in April, May or June, that is to say, more or less after the freezing period and thus hard seed is of considerable significance, especially in the case of Red Clover sown for an ordinary one year ley. It is probably of less significance in the case of White Clover sown for 2-4 year leys and for Late Flowering red clover sown for leys of similar duration, for if the seed does not germinate during the spring in time to contribute to the first year's herbage it is likely to germinate after the freezing period of the following winter and early spring and will contribute to the herbage of subsequent years.



perhaps more importance, than germination and purity. There seems to be little doubt but that, generally speaking, locally grown seed or at least seed harvested in countries no warmer or but little warmer than the district where the seed is to be sown, is likely to produce plants which will "stand" the longest and in many instances produce the heaviest hay crops in the first year after sowing.

(2) Investigations were therefore undertaken with a view to establishing a "Nationality test" for Red Clovers. It is only legitimate to draw provisional conclusions from the results brought forward in this paper. It was only possible to experiment with comparatively few nationalities, and to deal exhaustively with two seasons' harvests<sup>1</sup>. The tests described, however, proved to be informing and seem to indicate that the seed of certain groups of nationalities can be more or less distinguished from that of other groups.

(3) The work described had an important bearing on the quality of red clover seeds in general, and in many of its phases was complementary to investigations undertaken by other writers.

The following statement which applies equally to clovers of all nationalities would appear to be justified by the investigations undertaken and (or) by the works referred to in the body of the paper.

(a) The violet, mauve and mottled seeds, are heavier than the yellow, and both are heavier than the brown seeds in a sample.

(b) There is little or no difference in the germinating capacity between the violet-cum-mottled seeds and the yellow; but both of these germinate better than the brown. Well-formed and plump brown seeds germinate better than ill-formed and shrivelled brown seeds, but even the former do not germinate as well as violet and yellow.

(c) Yellow seeds are slightly more resistant to incubation at 40° C. than are violet-cum-mottled and at optimum temperatures frequently germinate rather more quickly. Brown seeds (well-developed) are considerably less resistant to incubation at 40° C. than violet or yellow; whilst brown seeds (ill-developed) are almost incapable of germination at 40° C.

(d) The amount of "hard" seed found amongst yellow, violet-cum-mottled and brown (well-formed) seeds although often markedly different in individual samples does not on the average vary very much, but is probably least among the violet. Brown (ill-formed) seeds do not, however, give rise to an appreciable amount of hard seed.

(e) Incubation at single constant temperatures above the optimum

<sup>1</sup> It is evident also that samples of the same nationality must vary considerably amongst themselves according to the particular district in which they were grown.

up to 35° C. does not on the average decrease the amount of hard seed, but at 40° C. the amount of hard seed is usually somewhat less. Individual samples are, however, met with which give very appreciably less hard seed at 30° C. and 35° C. than at 20° C. or 25° C. This suggests that "hardness" is a matter of degree. That this is so is borne out by the fact that "hard" seed will continue to germinate slowly when incubated for a period of months.

Incubation at a fluctuating temperature of 20° C. to 40° C. did not on the average much hasten the germination of hard seed. In this connection the conclusions of Harrington<sup>(6)</sup> were cited; namely, that "Alternations of temperature cause the softening and germination of many impermeable clover seeds when a temperature of 10° C. or cooler is used in alternation with a temperature of 20° C. or warmer."

It would appear also that incubation with a constantly over-saturated seed bed does not obviate hardness, but evidence in connection with routine seed testing suggests that by slightly fluctuating the moisture content of the seed bed the amount of "hard" seed may in some cases be slightly reduced. The small seed taken from a sample usually gives a slightly higher percentage of "hard" seed than does the large.

(f) Small and light seed, if well developed, does not, as such, differ in germination from large and heavy seed. The small seed extracted from a pure sample (representing an unblended bulk) will usually germinate as well as the large and is often slightly more resistant to incubation at 40° C. than the large.

(g) Samples vary very much in their power of resistance to incubation at temperatures above the optimum (about 20° C.-22° C.). Samples in good condition and of high germinating capacity being altogether more resistant than those in poor condition and of low germination. Samples three or more years old (although originally excellent) appear to be less resistant to incubation at 35° C. and 40° C. than do those from a current harvest with a poor capacity of germination due to adverse weather conditions.

(h) The degree of resistance to incubation at high temperatures is probably a better index of vigour than energy of germination—samples with practically similar energies of germination may exhibit very different degrees of resistance to incubation at 35° C. and 40° C. As a general rule, however, those samples which germinate most rapidly at 20° C. will also attain to the highest germinations at 35° C. and 40° C.

4. It is possible as a result of the work undertaken to draw up a scheme for conducting a critical nationality test on any particular sample of red clover. It has been shown that Chilean, Canadian, French

and Italian clovers all tend to have higher rapidities and energies of germination and to be more resistant to incubation at high temperatures than British. A good energy result therefore, although denoting vigour, may also imply at least admixture with a foreign clover; and therefore may afford reason for refusing rather than accepting a sample. It is just these attractive looking samples which give high energies of germination that should be subjected to the nationality test described hereunder.

(a) Examine not less than 2 oz. of the sample with a view to making a complete list of all the weed and other seeds present (if any). This should be done by passing the whole sample over the "Dodder Machine." The presence or absence of diagnostic weed seeds, and the combination of weed seeds, will afford some evidence, but not necessarily conclusive evidence. Excess of the large Chilean dodder, in a large seeded sample, with a high proportion of yellow seeds would suggest a Chilean clover, a few seeds of the Chilean dodder in a smaller seeded sample would be compatible with Canadian seed. Chilean dodder, however, in small traces may be met with in seed harvested in this country<sup>1</sup>.

(b) Ascertain the grain-weight of the seeds, and the proportion of yellow to brown seeds. This will aid in the differentiation between Chilean and English samples on the one hand, both being of high or relatively high grain-weight, the former having a high percentage of yellow and the latter of brown seed. French, Italian and Canadian seeds on the other hand will have lower grain-weights. The above tests will not necessarily be sufficient to detect a blend of two nationalities and should be supplemented as follows:

(c) Separate the sample into two grades "large," and "small," by passing over a 1.5 mm. sieve. Ascertain the proportion of brown to yellow seeds for each grade separately. Germinate each grade separately both at 20° C. and at 40° C. If the proportion of "large" to "small" seed is very different to the average of British samples it is not unlikely that the sample consists of a blend, although the blend may be the result of bulking the cleanings (= small seed) from one English "lot" with another un-cleaned or only partially cleaned "lot." If the proportion of yellow seeds is considerably higher in the case of small seeds than the large, it would be legitimate to suspect that the small seed consisted largely of (1) Italian, (2) Canadian, or (3) French seed. The separation of English from Chilean seed is not so complete by sieving, but a considerably higher proportion of yellow seed amongst the large

<sup>1</sup> The writer has found a few seeds of Chilean dodder in a sample of Red Clover harvested in Montgomeryshire.

seed would be confirmatory evidence of the presence of Chilian seed. If the germination of the large and small seed was decidedly different, it would be highly probable that the sample was a blended one, although not necessarily of different nationalities. If, however, the small seed proved to be considerably more resistant to incubation at 40° C. than the large, the implication would be that the sample consisted of a greater or less amount of Canadian, Italian or French seed. Consequently, if such a sample gave a higher proportion of yellow amongst the small seed than amongst the large and if weed seeds diagnostic of Canada, France or Italy were also found, it would be almost certain that one of these nationalities contributed to the bulk.

(d) It would therefore appear that it is often possible to detect a blended sample, and in many cases also to form a very shrewd opinion as to what nationalities contributed to the bulk. It must be emphasised, however, that no one test—comparable to a chemical test—can be applied to clover seeds which would give absolute evidence as to country of origin. The tests described, however, afford strong circumstantial evidence, and should always be applied to samples of a suspicious character offered for sale as “English.” There is not the least doubt that a very appreciable amount of “English” clover has been in the past adulterated with that of foreign origin<sup>1</sup>, and even if a few genuine English samples were to be rejected by purchasers on the results given by a critical nationality test—the gain would be enormous if farmers would refuse delivery of “English” seed which in the opinion of a competent analyst was suspect as to place of origin.

My thanks are due to my former colleagues at the Seed Testing Station for valuable help in connection with that part of the work conducted in London. I am, in particular, indebted to Miss M. Adams, B.Sc., who was responsible for all the tests carried out in reference to grading the samples on a size basis, and for numerous tests conducted at different temperatures. I owe it to the energy of Miss Adams and of Miss Hopkin that it was possible to conduct all the necessary tests during the comparatively short time available for investigational work of this character.

<sup>1</sup> Chilian dodder was found in 30 samples of Red Clover purporting to be of English origin during season 1917-18 at the Food Production Department's Seed Testing Station, and a large number of samples contained weed seeds suggestive of foreign origin (16). Over 50 per cent. of the Red Clover samples examined by the present writer in 1913 contained weed seeds suggestive of the foreign origin of a part at least of the samples containing them (13). In 1915 a sample of Red Clover offered for sale as Welsh was tested by the author at Aberystwyth; it was of a suspicious appearance, and eventually seeds of Chilian dodder were found in the 3 lb. bulk. It was returned to the vendor by the purchaser (14).

My thanks are also due to a number of Seed Firms who kindly sent me samples of different nationalities to Aberystwyth, and especially to Mr H. H. Dunn, of Bournemouth and Salisbury, who, at considerable pains, procured for me a large number of genuine English-grown samples from different counties. I am equally indebted to Mr Dymond, Seed Analyst, Department of Agriculture, Ottawa, who kindly sent me samples of Red Clover from Canada, and to Messrs Burton and Oldershaw who were good enough to procure samples from Somerset and the Eastern Counties respectively, and to Mr Flattely, who kindly forwarded me samples from Italy.

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## THE RELATION OF PROTEIN CONTENT TO VARIETY TYPES IN AMERICAN WHEAT.

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Two factors are of chief importance in wheat production, namely high protein content and large yields. Aside from hybridization, the first work of the wheat breeder is to isolate those strains which possess at least these two indispensable characteristics. Since the protein forms the chief part of the gluten, the wheat breeding problem is mainly concerned with high-gluten wheats.

As Thatcher says:

Wheat and its products are valued as food according to the amount of protein which they contain, since other food materials, such as starch, fats or sugar, may be obtained more economically from other sources (9, p. 28).

Starch is just as necessary an ingredient, and possibly of greater food value. But starch can be grown and supplied by many other plants just as easily, and perhaps more cheaply than by wheat. If it were possible to grow wheat so rich in protein that it would yield flour containing too small a proportion of starch for proper baking qualities, this deficiency could easily be overcome by adding starch from some other source (*ibid.*, p. 9).

For the most part, in tests made of wheat varieties, selection is based entirely upon yield, sometimes supplemented, however, by milling and baking tests. As stated by Stewart and Hirst (8):

The grain buyers at the great central wheat markets attempt to standardize the grain brought, by classifying them as No. 1, 2, 3, etc., and base their classification almost wholly upon certain physical characteristics, such as hardness, plumpness, colour of berry, etc.,—characteristics which may not be the controlling ones in determining the value of the wheat for flour production. It would seem that reliable information regarding the actual moisture content of the wheat, and the protein content and actual baking value of the flour, would be more reliable guides in the purchase of wheat (p. 116).

Although the percentage of protein in wheat is not an absolute gauge to its milling and baking qualities, yet, as Bailey says(1):

The percentage of crude protein is of considerable value in indicating the relative strength of flours, and other things being equal, the baking strength of a sound, high-grade flour is usually high, if the percentage of protein (gluten) is high, and low when the opposite is true, although there are frequent exceptions to this general rule (p. 19).

A similar point of view is expressed by Harper and Peters(2):

Flours containing a high percentage of gluten, other conditions being equal, are preferred by bakers, and in some markets such flours sell at a higher price. Protein is also the more valuable constituent of wheat from a food standpoint; therefore, both from a baker's standpoint, and as a food product, wheats rich in protein are to be preferred. *It is important, therefore, in selecting and developing a variety of wheat, to take into consideration the content of nitrogen, as well as the yield, milling qualities, etc.* (p. 7. Italics inserted).

Le Clere says(3):

It may be well to emphasize the fact that the countries which are the great buyers of wheat purchase generally on the basis of protein content, that is, on the basis of weight per bushel, and the weight per thousand grains; while in some localities, wheats are bought on the basis of the chemical analysis itself. It is therefore of the utmost importance, in order to retain our foreign markets, and maintain our commercial supremacy and national reputation as producers of high-grade wheat, *that the closest attention be paid, not only to the production of high yielding wheats, but also to the cultivation of varieties having a high protein content, with a view to growing wheats which combine these two characteristics—high gluten content and large yields* (p. 222. Italics inserted).

That the problem of high-yielding wheats of high protein content is a real one to wheat breeders, is further maintained by Thatcher(9):

Unfortunately, it is just those conditions which produce plump, heavy grains, giving high yields per acre, which result in soft, starchy, low protein grains. The problem which confronts the wheat industry of this state is how to produce grains which, under our favourable conditions for long ripening periods and heavy yields per acre, will manufacture and store up sufficient protein, to yield flour of high enough gluten content to make it desirable for bread-making purposes (p. 7).

The situation as it stands, with respect to wheat varieties, is well stated by Stewart and Greaves(7):

No single variety now possesses combined, the desired characteristics of yield, protein content, flour yield, weight per bushel, and the most desirable milling qualities (p. 274).

It will be necessary to consider in order the relation of the protein content (1) to external factors, and (2) to the variety type.

## 1. THE RELATION OF PROTEIN CONTENT TO EXTERNAL FACTORS.

It is still an unsolved problem in wheat breeding at what point the influence of climatic and edaphic factors ceases, and the specific constitution of the variety asserts itself independently. The solution of the problem is demanded in all regions growing soft wheat. The matter has been thus stated by Woods and Merrill(12), citing Schindler:

In regions with a moist, warm climate, the fruiting period is prolonged, and abundant quantities of starch are formed in the large leaf surfaces, which such a climate produces on the wheats. The starch thus formed, is all transferred to the berry, which is thus filled up, as is shown externally, by the broadly expanded form. Such a wheat is relatively rich in carbohydrates and poor in protein. On the other hand, a hot dry climate shortens the time for starch transference, and the native wheats of such a climate are, in general, richer in protein, and lower in carbohydrates (pp. 152-153).

So far as climatic factors are concerned, it is sufficient to say that a long growing season, with abundant precipitation, favours the development of a starchy kernel, while a short, dry growing season, especially in the spring, in the case of winter wheat, favours the development of grains high in protein, and consequently hard and glutinous. Quoting Bailey(1):

As early as 1857, Lawes and Gilbert observed that *a long ripening period after heading gave a plump kernel with a low percentage of protein, while a shorter ripening period resulted in increased protein content* (p. 10. Italics inserted).

Thatcher, in 1907(9), held that the chief factor influencing percentage variation in the constituents of wheat *is the length of time between flowering and the ripening of the seed*. Summarizing, he says:

In brief, it appears that any climatic conditions which tend to shorten this time, such as a lack of available moisture, or a hot wind, result in high-protein wheat, while conditions which tend to lengthen the ripening period, produce starchy, low-protein grains (p. 7).

In 1911, Thatcher further says(10):

Many agricultural writers are now contributing articles in support of the view that climatic influences alone are responsible for differences in type of the wheat. Some of these writers are of the opinion that the length of the growing period of the grain, instead of the rapidity of ripening alone, is the determining factor in the kind of grain. In opposition to this, however, are the opinions of plant physiologists recently published, that the proteins of wheat are largely elaborated early in the plant's growth, and practically cease to increase in amount after the plant blossoms, while the manufacture of starch continues as long as any part of the plant remains



green. If, therefore, the period of time after blossoming is lengthened by any climatic conditions, the elaboration and storage of starch would be increased, and the resultant grain would be more starchy or softer (p. 43).

The writer's own observations<sup>(5)</sup> are in general accord with those of Lawes and Gilbert, and of Thatcher's 1907 statement, *provided the special case of "yellow berry" in hard winter wheat is the same as the general case of soft as related to hard wheat.* The data are not conclusive, if the details alone are considered, because of conflicting cases in the extreme numbers. A general survey of the results for the two crop years therein reported, however, may be more accurate as a means of gauging the matter for purposes of scientific inference, than the details would be. The averaged data are as follows:

Table I\*.

No. of days, Mar. 1 until ripe		Average percentage of yellow berry		Number of cases	
1906	1907	1906	1907	1906	1907
118	125	33	39	128	127

\* Kansas Experiment Station *Bulletin* 156, p. 20.

The above data show the lower percentage of "yellow berry,"—soft starchy grain,—that is to say the higher percentage of hard, glutinous kernels, to be associated with the shorter spring period.

Of the edaphic factors affecting the protein content of wheat, the most important is the water supply. In this connection, the data furnished by Bailey<sup>(1)</sup> regarding the relation between the precipitation between April 1st and September 1st, 1911, and the protein content of wheat and flour, in the case of hard spring wheat growing in sixteen counties in Minnesota are instructive:

Table II\*.

				Protein %	Protein %
Rainfall				Wheat	Flour
Between 12-13 inches	...	...	...	14.93	13.47
14-15 "	...	...	...	13.73	12.61
16-17 "	...	...	...	14.21	12.56
18-19 "	...	...	...	13.42	12.29
20-21 "	...	...	...	12.88	11.87
22-24 "	...	...	...	11.63	10.65

\* Minnesota Experiment Station *Bull.* 131. Compiled from Table VII, pp. 36-7.

The lowering of the protein content, concomitantly with the higher rainfall, is evident.

The general influence of dry soil conditions upon hardness and protein content of the grain has been stated. The only way in which

the soil moisture supply may be radically altered is, of course, by irrigation. Turning to the statement of Stewart and Hirst(s):

In case of the irrigated varieties of wheat, as the amount of water applied decreases, the protein content increases. The protein content of the flour produced from the wheat which received no irrigation water, is one per cent. greater than that produced from wheat receiving an application of 25 inches, notwithstanding the fact that the seed wheat in both cases was the same, and the non-irrigated wheat was grown on land which had been irrigated in previous years. The moisture and dry gluten content of the flour produced from the irrigated wheat is considerably lower than that produced from either spring or winter dry-farm wheat (p. 149).

The direct effect of irrigation water on protein content is reported from Utah as follows:

Table III\*.

Precipitation	Protein %
25 inches ... ..	12.63
15 inches ... ..	12.92
No irrigation ... ..	13.62

\* Utah Experiment Station *Bull.* 125, p. 145. Flour analyses.

The relation of the protein content to climatic factors is well illustrated by the data from several wheat-growing areas in the United States, showing the amount of variation in protein, with respect to what may be called regional types. Taking first the general rough classification of wheats into "hard," "semi-hard" and "soft," we have the following data:

Table IV\*.

(Montana.)

Class	Protein %
Hard spring ... ..	11.36
Hard winter ... ..	10.02
Soft " ... ..	9.16

\* Minnesota Experiment Station *Bull.* 131 (1911), p. 42.

Table V\*.

Protein Content of Wheat and Flour (Utah).

Class	1907				1907-8				1908-9			
	No. of varieties	No. of Wheat varieties		No. of Flour	No. of varieties	No. of Wheat varieties		No. of Flour	No. of varieties	No. of Wheat varieties		No. of Flour
rd Winter	2	13-89	2	14-30	—	—	—	—	80	16-11	78	14-85
mi-hard "	10	13-91	9	13-44	—	—	—	—	9	16-74	9	15-08
lt "	1	12-40	1	11-99	—	—	—	—	27	16-62	27	13-85
rd Spring	—	—	—	—	2	18-21	2	18-53	—	—	—	—
" "	—	—	—	—	6	17-46	6	14-89	—	—	—	—
" "	—	—	—	—	7	16-67	7	16-23	—	—	—	—

\* Utah Experiment Station *Bull.* 125. Compiled from tables on pp. 148-9.

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The above tables show the general fact, which is sufficiently well known, that the hard wheats range higher in protein content than the soft wheats.

Following out this comparison of wheats for different regions of the country, we find, that as we go west from the Atlantic seaboard, the protein content of the wheat rises. This is unquestionably due to the general fact that in the western wheat areas the harder wheats are grown. The following table illustrates the matter:

Table VI\*.

Region	No. of analyses	Average % of protein
Atlantic and Gulf states ...	117	11.35
Middle states ... ..	91	12.50
Western „ ... ..	177	12.74
Pacific „ ... ..	20	9.73

\* Report of Chemist, Dept. Agric. 1884, p. 77. Reprinted in Maine Experiment Station *Bull.* 97, p. 153.

From the above table it is apparent that the protein content of wheat rises as we proceed from the eastern regions of higher precipitation to the relatively dryer areas of the middle and western states, except for the Pacific Coast region, where wheat is grown either by virtue of the winter rains or under irrigation. This is without taking varietal characteristics into consideration; the favourite wheats of the Pacific seaboard being soft, white varieties, which are characteristically low in protein.

Similar data are furnished by the analyses of the Maine Experiment Station:

Table VII\*.

Region of source	No. of samples	Average % of protein
Maine grown ... ..	16	12.20
Minnesota grown ... ..	25	14.09
Western grown ... ..	12	14.52

\* Maine Experiment Station *Bull.* 97, p. 156.

The figures in Table VIII, following, represent the results of the analyses of Minnesota-grown seed, as compared with the progeny grown in Maine from the Minnesota-grown seed as parents:

Table VIII\*.

Region of source	No. of samples	Average % of protein
Minnesota ... ..	5	14.41
Aroostook Co., Maine ...	5	13.21

\* Maine Experiment Station *Bull.* 97, p. 161.

The Kansas Experiment Station conducted a similar series of analyses of wheat from different states, with the following results:

Table IX\*.

Region of source	No. of samples	Average % of protein
Washington ... ..	5	10.25
Tennessee ... ..	4	10.46
Minnesota ... ..	6	11.96
Kansas ... ..	12	12.48

\* Kansas Experiment Station *Bull.* 177; averages from pp. 124-126.

The general data from Tables VI, VII, VIII and IX are in entire harmony with regard to the general proposition, that, as we proceed from the areas of greater rainfall of the eastern and Gulf states to the drier areas of the western and north-western states, there is a corresponding increase in the protein content of the wheat. *That this coincides also with the fact of the growing of different varieties in the different regions is further true.*

## 2. THE RELATION OF PROTEIN CONTENT TO VARIETY TYPE.

Narrowing the discussion down, from the matter of regional types, to that of "varieties," we have the following data, from the experiment stations of Minnesota, Washington, Utah and California:

Table X.

*Protein Content of Wheats from California, Utah, Washington and Minnesota.*

Variety	No. of samples	Average % protein
Propo* ... ..	5	10.64
Washington Bluestem ...	33	10.18
White Australian ... ..	42	9.89
Sonora ... ..	17	9.71
Little Club ... ..	52	9.35
White Club† ... ..	1	20.17
Wellman's Fife ... ..	2	17.45
Bluestem ... ..	3	17.11
Red Chaff ... ..	4	16.77
Lofthouse ... ..	5	16.06
Odessa ... ..	4	16.55

\* Five variety samples from California Ex. Sta. *Bull.* 212, p. 361.

† Twelve variety samples from Utah Ex. Sta. *Bull.* 103, pp. 260-262.

Table X (continued).

Variety	No. of samples	Average % protein
Turkey ... ..	5	16.46
Sonora ... ..	2	16.29
Whittington ... ..	2	16.10
Northcoate's Amber ... ..	1	15.93
Kofod ... ..	3	15.61
Gold Coin ... ..	4	15.11
Macaroni* ... ..	13	12.86
Bluestem ... ..	126	12.44
Red Allen ... ..	17	12.04
Jones' Winter Fife ... ..	43	11.61
Turkey Red ... ..	55	11.27
Little Club ... ..	65	10.75
Forty-fold ... ..	27	10.74
Red Russian ... ..	16	9.76

\* Eight variety samples from Washington Ex. Sta. *Bull.* 100, p. 36.

Table XI\*.

*Protein Analyses of Flour from Maine, Minnesota and Utah.*

Variety	Maine	Minnesota	Utah
Fife	13.03	13.74	15.99
Bluestem	11.69	11.51	15.52

\* Utah Ex. Sta. *Bull.* 103, p. 266.

Finally, to these data, may be added the analyses of varieties of bread and macaroni wheats made in South Dakota:

Table XII\*.

Type	1903*		1905†	
	No. of varieties	Average % protein	No. of varieties	Average % protein
Bread wheats ... ..	1	13.44	5	13.68
Northern or Russian macaronis	50	14.20	25	15.19
Southern or Mediterranean macaronis	30	14.51	17	16.14

\* South Dakota Ex. Sta. *Bull.* 82, pp. 23-26.

† *Bull.* 92, pp. 19-21.

The well-known fact that regional differences, that is to say, differences in the amount of precipitation, rate of evaporation, and probably also the heat factor during the ripening period, involve differences in the protein content of wheat is sufficiently shown by Tables VI to IX. The subsequent Tables, X to XII, seem to show that there is also an

unquestionable difference due to the fact of variety itself. On this point, however, there are conflicting views.

According to Le Clerc and Leavitt's investigations(4):

*Wheat of the same variety, obtained from different sources, and possessing widely different chemical and physical characteristics, when grown side by side in one locality, yields crops which are almost the same in appearance and composition. Wheat of any one variety, from any one source and absolutely alike, in different climatic conditions, yields crops of very widely different appearance, and very different chemical composition. The results so far obtained would seem to indicate that the soil and seed play a relatively small part in influencing the composition of the crops (p. 18. Italics inserted).*

Thatcher also says, regarding wheats grown in the state of Washington (10, p. 40), that the variation in composition for the wheats grown in the different districts "is somewhat greater than the differences between the averages for the different varieties," and that,

in other words, environmental conditions exert a greater influence in determining the quality of wheat than do variety characteristics. For this reason, a knowledge of the conditions under which the wheat is grown is more essential to a correct judgment as to the quality, than is the variety name. There may be, and usually are, greater variations in quality in the same variety when grown in different localities, than between different varieties grown in the same locality (p. 40).

On the other hand, Woods and Merrill(12), on the basis of their Maine experiments, say:

Chemical composition depends more upon the variety cultivated, than upon soil and climate, although the influence of the two latter is by no means overlooked.

The fact that varietal characteristics are fundamental, and can be counted upon as a basis for the breeding of wheat, is well known to all who have conducted experiments with the grain. Thatcher himself says(10):

Of the varieties most commonly grown, Bluestem still retains its position at the head of the list, carrying the highest average protein content. Red Allen, though not so commonly grown, is next in relative rank in protein content and gluten test (p. 23), and again (10):

For example, Bluestem wheat grown in any given locality of average conditions, will carry about one-sixth more protein, or yield that much higher gluten test, than Little Club grown side by side with it (p. 40).

Commenting further, the general statement is made regarding Washington varieties(10):

Eliminating the macaroni varieties then, it is apparent that Bluestem and Red Allen stand in a class by themselves, as superior to all other varieties commonly grown. Turkey Red falls in a second class along with Jones' Winter Fife, having

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qualities slightly inferior to those of Bluestem. Little Club and Forty-fold form a third class of lower grade, and Red Russian is lowest in food and milling qualities, of any of the common varieties (p. 37).

However, it is undoubtedly true, as is further stated by the same author(9):

Within any given variety, there appear wide variations in composition. These variations appear to be closely connected with the climatic conditions existing in the several localities. In general, the dryer the climate, the lower the percentage of moisture, and the higher the percentage of protein (p. 19).

Here the evident conflict between the quality of the grain, as expressed by the protein content, and the yield is plainly remarked upon in these words(10) (p. 38):

These three varieties (Little Club, Forty-fold and Red Russian), are, however, those which are noted for high yielding capacity, and on that account will continue to be grown over large areas.

From the experimental work done in Utah, Stewart and Greaves(7) offer further a piece of negative evidence regarding the behaviour of varieties grown in that state from 1904-1908, with respect to their protein content, as follows:

It is noteworthy that *the protein content of Gold Coin is the lowest of any variety grown in the arid farms* (p. 256, italics quoted).

Summarizing the data surveyed, it appears:

1. *That the primary factors in determining the composition of wheat are climatic, but that,*
2. *Varietal differences do exist which manifest themselves in higher protein content in certain wheat varieties, where grown side by side with others in different situations.*

In the cases cited herein, the varieties were not pure strains, or at least were not spoken of as such. The writer, in the course of an investigation upon the relation of hardness of wheat to its protein content, had the latter determined for ninety-four pure strains, or "pure lines." These strains were all derived, by a single head selection in each case, from commercial varieties of wheat. The amount of variation in protein content amongst these strains is measured by the standard deviation ( $\sigma$ ), or error of mean square. Comparing the standard deviation for these ninety-four different pure strains, grown in the same field the same season, with the same constant for 30 different commercial varieties (not pure strains), grown at the Kansas Experiment Station(11) (pp. 114-117), and with the same constant for each of a number of varieties of Washington and California wheats, we have the following:

Table XIII.

Where grown	Wheat under experiment		Standard deviation ( $\sigma$ ) in percentage of protein
Kansas*	Pure strains	94	0.8318
" <sup>†</sup>	Commercial varieties	30	1.27
California <sup>‡</sup>	Club	25 strains	2.54
"	Australian	25 "	1.87
"	Propo	20 "	1.58
Washington <sup>§</sup>	Bluestem	43 "	2.21
"	Turkey Red	19 "	1.28
"	Little Club	27 "	1.54
"	Jones' Winter Fife	10 "	0.73
"	Forty-fold	10 "	0.56

\* Manuscript.

<sup>†</sup> *Bull.* 177, pp. 114-117.<sup>‡</sup> *Bull.* 212, pp. 164-167.<sup>§</sup> *Bull.* 84, pp. 20-27.

From this table it is evident that there are varietal characteristics with respect to protein content, some varieties manifestly varying more than others in this respect, as is shown by the standard deviation. A higher standard deviation may indicate that the variety in question was not very pure, and that the strains separated out belong to widely different types, or else that in such cases there exists a wide range of physiological adaptation of the plants, in respect to the factors operating to affect the protein content.

It is evident that the mathematical degree of variation in protein content, as expressed by the standard deviation, may be a suggestion as to the relative adaptability of the variety itself. At all events, the decided *difference in the degree of variation* in protein content in different varieties of wheat is, in itself, an indication that there is a greater degree of stability in that respect in some races of wheat than in others, whatever the reason for it may be. This fact confutes the idea that variation in the protein content is a phenomenon dependent upon climatic conditions alone, and indicates that the breeding of wheat for protein content is scientifically feasible. Considering the fact that different races of corn, such as dent and flint, differ widely in their protein content, and that the same holds good of rye and oats, there is no reason why distinct races of wheat, even within the so-called "hard" wheats, may not be originated, which are superior in that respect to those existing to-day.

Returning to Table XIII, a further interesting fact is developed, that *the wheats with the highest standard deviations*, in other words, *the wheats varying most in respect to protein content*, are also, in California and Washington at least, the wheats most widely grown. According to Shaw



and Gaumnitz<sup>(6)</sup> (p. 317), Club Wheat is at the head of the list of varieties most widely grown in California. In Washington, according to Thatcher<sup>(10)</sup> (p. 25), the seven wheats most generally grown are, in the order named, Bluestem, Little Club, Turkey Red, Jones' Winter Fife, Forty-fold, Red Allen, and Red Russian. The first four of these, according to Table XIII, stand in the order named, with respect to the size of their respective standard deviations for percentage of protein. This complete coincidence of high variability in protein, as expressed by the standard deviation, with the extent to which a variety is grown in a region, may possibly be significant. It may indicate a greater adjustability to varying local conditions, and a wider range of adaptiveness. A higher standard deviation in respect to protein at once indicates, *ipso facto*, a correspondingly higher variation in starch. Wheat, of course, is grown primarily for yield, but in the last analysis those wheats are usually grown which are the best bread wheats that can be raised in the locality. This means, in every case, wheats that stand relatively high in gluten, i.e. in protein content. Hence the yield factor alone is not determinative in wheat growing.

Roughly stated, of course, the reason for the predominance of one variety over another, in a given region of territory, is summed up in the statement that it "does well"—i.e. that, in general, it surpasses others in yield, thriftiness, and grading of the grain. When we come to investigate narrowly the scientific factors concerned, it would appear, from the data herein, that one unconscious selective factor at least is a certain wider physiological adaptability, which finds partial expression certainly in degree of plasticity or mobility in relative starch-protein production.

Such, at least, the data with respect to the standard deviation seem to indicate. The data from the Kansas analyses are in another category. In these cases, we do not have separate standard deviation determinations for different varieties, but for two groups of wheats—94 pure strains in the one case, and 30 commercial varieties in another. The lots in both these cases were all hard, or semi-hard, wheats, and the data indicate simply the range of variation in protein *amongst* varieties of wheats, which is less than the range of variation *within* such soft varieties as Club, Australian, and Propo.

## SUMMARY.

1. Protein in wheat is the most important constituent, and therefore the chief constituent to breed for. No wheat variety possesses at once combined the desired characteristics of high protein, high yield, maximum flour production, and maximum bushel weight.

2. So far as climatic factors are concerned, a short, comparatively dry growing season, especially in the spring, in the case of winter wheat, favours the development of grain rich in gluten, and hence high in protein.

3. The most important ground factor in determining the starch-protein ratio is the water supply. The protein content has been found to vary from 11.63 per cent. under 22-24 inches of rainfall to 14.93 per cent. under 12-13 inches (Minnesota); and from 12.63 per cent. under 25 inches of irrigation to 13.62 per cent. under no irrigation (Utah).

4. With regard to regional types of wheat, the range of variation in protein content is from as low as 9.16 per cent. (soft winter from Montana) to 13.89 per cent. (hard winter from Utah).

With respect to regions of the country, variation in protein percentage ranges from 11.35 per cent. in the Atlantic and Gulf states to 12.74 per cent. in the western states, while the wheats of the Pacific Coast run as low as 9.73 per cent. Maine experiments show an even wider range, where the same wheats were grown in Maine and Minnesota, running from 12.20 per cent. of protein for Maine to 14.52 per cent. for the western-grown wheat.

5. Besides differences in the protein content of wheat owing to locality, there are differences due to variety itself. Speaking generally, the bread wheats are the lowest (13.44 per cent.—13.68 per cent.); the Russian durumms next (14.20 per cent.—15.19 per cent.), and the Mediterranean durumms highest (14.51 per cent. —16.14 per cent.). Within the bread wheats, there are varietal differences ranging from as low as 9.76 per cent. in Red Russian to 12.44 per cent. in Bluestem (Washington); and from 15.11 per cent. in Gold Coin to 17.45 per cent. in Wellman's Fife (Utah). Flour analyses from Maine, Minnesota and Utah show Fife to exceed Bluestem by an average of 1.35 per cent. (from Table XI). In Washington, in any locality, Bluestem has been found to carry one-sixth more protein than Little Club. In Utah, Gold Coin was constantly the lowest in protein of any variety.

6. The variation in protein content is measured by the error of mean square, or "standard deviation." It appears that, computing the data from California and Utah, the wheat varieties most widely grown

in those states are the ones that turn out, according to the writer's computation, to have the widest variability in respect to their protein content, i.e. which have the highest standard deviation. This is true of Club wheat in California, and, in the order named, of Bluestem, Little Club, Turkey Red, Jones' Winter Fife, and Forty-fold in Washington (see Table XIII).

7. The conclusion is, since variability in protein content is a varietal characteristic in wheat, that, in breeding for general purposes, wheat strains should be sought out which vary greatly in this respect, rather than those which are rigid. In other words, greater flexibility in the starch-protein ratio means greater climatic adaptability. In breeding for a limited locality, wheat with a maximum protein content, and with the least possible variability with respect thereto, is to be sought; the variability in this respect being computed in terms of the error of mean square or standard deviation.

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# A METHOD FOR ESTIMATING THE NUMBER OF ACTIVE PROTOZOA IN THE SOIL.

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## INTRODUCTION.

THE present writer has pointed out in a previous paper<sup>(1)</sup> the importance of finding means for estimating the number of protozoa in the active-noneystic-condition in a soil sample. Up to the present, with few exceptions, the total number of protozoa, irrespective of their condition, has been ascertained, and no method has yet been evolved giving an approximately accurate estimate of the number in an active condition.

## PREVIOUS WORK.

Martin and Lewin<sup>(2)</sup> were the first to show that in normal soil there existed an active trophic<sup>1</sup> protozoal fauna. This they did by two methods. In the first, soil was stirred into picric acid contained in a porcelain dish. A film rose to the surface containing protozoa, which could be collected on cover glasses. This method gave fair results as regards small flagellates, small amoebae and thecamoebae. The second method consisted in bubbling a stream of air through a suspension of the soil to be tested and allowing the bubbles to break on to cover glasses fixed at the surface of the suspension. Thus they showed that Rothamsted soil contains active amoebae and flagellates.

These observations are interesting and important in demonstrating the presence of active soil protozoa, but give no clue as to their numbers.

Cunningham<sup>(3)</sup> attacked the problem in a somewhat different manner. As cystic protozoa are more resistant to high temperature than active ones, he suggested heating to 58° C. in order to kill all active organisms and leave cysts uninjured, thus allowing a distinction to be made between these two conditions. This was adopted in combination with a dilution method. Two sets of dilutions were made, the first with untreated soil and the second with soil which, in the 1/100 dilution, had been heated to 58° C.

<sup>1</sup> Active means capable of movement and trophic means capable of feeding. As the states usually synchronise protozoologists use the terms synonymously.

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Experiments indicated, however, that a temperature of 58° C., while absolutely essential if one wished to be certain that all active forms were killed, also kills a large number of encysted protozoa. The method was therefore impracticable.

Drying the soil or treating it with 0.5 per cent. caustic potash, though showing that an active protozoal fauna existed, proved unsuitable for estimating the number of cysts and active forms.

Koch<sup>(7)</sup>, Itano and Ray<sup>(8)</sup> and Kopeloff, Lint and Coleman<sup>(8)</sup> have described direct methods for doing this, but none are entirely satisfactory for routine work.

#### HYDROCHLORIC ACID METHOD.

The enumeration of the active forms can be obtained by the use of hydrochloric acid, in conjunction with the dilution method in use at Rothamsted.

Cropper and Drew<sup>(2)</sup> have already found that the cysts of a soil amoeba—species not given—are able to withstand 48 hours action of a 2 per cent. solution. The HCl used was B.P. pure 31.8 per cent. Goodey<sup>(5)</sup> has also shown that hydrochloric acid does not dissolve the cyst wall of *Colpoda cucullus*. In the present investigations mixed cultures of protozoa from the soil were used, including the following species: *Cercomonas* sp., *Oicomonas termo*, *Monas vulgaris*, *Amoeba glebae*: *Vahlkampffia* sp., *Colpoda cucullus*, *Colpoda steinii*, *Gonostomum affinis*. In all cases it is found that the active forms are killed while the cysts are unaffected. Counts made before and after treatment, therefore, give estimates of the respective numbers in the two conditions.

#### EXPERIMENTAL DETAILS.

##### CONTROL EXPERIMENTS.

*Microscopic examination.* These experiments were to determine the effect of varying strengths of hydrochloric acid on protozoa in the active condition. Cultures of the various flagellates, amoebae and ciliates in the active stage were subjected to the action of HCl, of the strengths 0.5 per cent., 1 per cent., 2 per cent., of the ordinary variety of 1.15 sp. gr.<sup>1</sup> In all cases the organisms were almost instantaneously killed as shown by their sudden cessation of movement, followed by disintegration. There is no doubt that hydrochloric acid of the strengths stated kills all the active forms of protozoa investigated. Barratt<sup>(1)</sup> has also shown that

<sup>1</sup> The titration value is as follows: 10 c.c. 2 per cent. requires 18.9 c.c. N/10 NaOH.

0.0004 N. HCl will cause the death of *Paramoecia* in one minute. Cysts appeared unaffected by the treatments, but they might have been killed without showing any outward sign. To test this two methods were used: a rapid eosin method, to which, however, some exception might be taken on theoretical grounds, and a more detailed excystation method, to which we believe no exception can be taken. Kuenen and Swellengrebel state that dead protozoan cysts are coloured red under the action of dilute eosin while living ones remain colourless. This was found to be the case with the cysts of *Entamoeba histolytica* by Wenyon and O'Connor(10) and the present writer. Such a rapid method of detecting dead cysts is naturally of great use and was therefore tested on the cysts of soil protozoa. Cysts were tested with a 0.125 per cent. watery solution of eosin. In some cases the cysts remained colourless for as long as half an hour. Experiments at longer intervals were not made. Excytation showed that these colourless cysts were alive. Cysts from the same cultures were then killed either by boiling or heating at 85° C. for one hour, or else they were placed in normal solutions of strong acids for a quarter of an hour. Excytation experiments demonstrated that such treatment caused the death of cysts. When these dead cysts were placed in the watery solution of eosin they at once became uniformly coloured. In the next series of experiments cysts of amoebae, flagellates and ciliates treated with 0.5 per cent., 1 per cent., and 2 per cent. hydrochloric acid (sp. gr. 1.15) for 12 hours and 24 hours respectively were tested for viability by this eosin method. The cysts did not take up the stain and were therefore regarded as living.

Microscopic examination therefore showed that active forms of amoebae, flagellates and ciliates were killed by the action of hydrochloric acid in strengths ranging from 0.5 per cent. to 2 per cent.: but that the cystic forms, or at any rate the large majority of them, could withstand this treatment for at least 24 hours. The different reactions of dead and living cysts to dilute eosin obviously depend on changes in the permeability of the cell membrane. As our knowledge of these changes is scanty and somewhat chaotic, perhaps too much reliance should not be placed on the method. Nevertheless it is very useful on account of its simplicity and rapidity in giving results, and if checked by other experiments is well worthy of general use.

*Excystation tests.* In these experiments suspensions containing a known number of active and cystic amoebae, flagellates and ciliates were made. The number per cubic centimeter was calculated by the method previously described(4). The suspensions were then treated with 1.5 per

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cent. HCl (sp. gr. 1.15) acting overnight and the following morning suitable dilutions of 1 c.c. of the suspensions were plated on to agar. It was found unnecessary to wash the protozoa entirely free from acid after the treatment as excystation will take place in the presence of .02 per cent. of the hydrochloric acid, an amount considerably in excess of that left after the dilutions have been made. In Table I are given the results of some of these experiments. It demonstrates very clearly that, by the addition of hydrochloric acid in suitable strength to a suspension of protozoa, the active forms are killed, leaving the cystic one alive, and that this occurs in types of protozoa common to the soil.

Table I.

Suspension	Number of organisms per c.c. found by direct count		Number of organisms after treatment as found by dilution method	
1.	Amoebae (cysts)	35,000	Amoebae	30,000
	" (active)	20,000		
	Flagellates (cysts)	170,000	Flagellates	150,000
	" (active)	680,000		
2.	Amoebae (cysts)	80,000	Amoebae	70,000
	" (active)	50,000		
	Flagellates (cysts)	45,000	Flagellates	40,000
	" (active)	266,000		
	Ciliates (cysts)	45,000	Ciliates	35,000
3.	" (active)	35,000		
	Amoebae (cysts)	40,000	Amoebae	35,000
	" (active)	100,000		
	Flagellates (cysts)	250,000	Flagellates	250,000
	" (active)	400,000		
4.	Ciliates (cysts)	75,000	Ciliates	60,000
	" (active)	50,000		
	Amoebae (cysts)	40,000	Amoebae	30,500
	" (active)	25,000		
	Flagellates (cysts)	175,000	Flagellates	170,500
5.	" (active)	0		
	Ciliates (cysts)	12,500	Ciliates	10,000
	" (active)	5,000		
	Amoebae (cysts)	25,000	Amoebae	20,000
	" (active)	100,000		
5.	Flagellates (cysts)	200,000	Flagellates	160,000
	" (active)	150,000		
	Ciliates (cysts)	50,000	Ciliates	45,000
	" (active)	30,000		

It will be noted, however, that in each experiment the number of organisms recovered alive after the treatment is usually a little less than

was expected. A discussion as to the reason for this is given later. The final series of control experiments were made upon soil containing protozoa. Ordinary Rothamsted soil was sterilised in the autoclave under 15 lbs. pressure for half an hour, and to this soil was then added a counted suspension of protozoa in all stages of development.

It was then treated with 2 per cent. HCl<sup>1</sup> overnight. Suitable dilutions were made and plated on to agar. Fifteen such experiments were performed, a representative five of which are given in Table II.

Table II.

Sample	Number of organisms per gram of soil		Number of organisms after treatment as found by dilution method	
1.	Amoebae (cysts)	25,000	Amoebae	25,000
	" (active)	40,000	"	"
	Flagellates (cysts)	100,000	Flagellates	95,000
	" (active)	100,000	"	"
	Ciliates (cysts)	32,500	Ciliates	30,000
2.	" (active)	5000	"	"
	Amoebae (cysts)	96,800	Amoebae	95,000
	" (active)	50,250	"	"
	Flagellates (cysts)	560,000	Flagellates	500,000
	" (active)	130,000	"	"
3.	Ciliates (cysts)	10,000	Ciliates	10,000
	" (active)	35,000	"	"
	Amoebae (cysts)	15,000	Amoebae	12,500
	" (active)	20,000	"	"
	Flagellates (cysts)	45,000	Flagellates	10,000
4.	" (active)	90,000	"	"
	Ciliates (cysts)	15,250	Ciliates	10,000
	" (active)	35,000	"	"
	Amoebae (cysts)	2500	Amoebae	2250
	" (active)	4000	"	"
5.	Flagellates (cysts)	1500	Flagellates	1000
	" (active)	6500	"	"
	Ciliates (cysts)	25,400	Ciliates	20,000
	" (active)	5000	"	"
	Amoebae (cysts)	645,000	Amoebae	600,000
	" (active)	537,000	"	"
	Flagellates (cysts)	1000	Flagellates	900
	" (active)	1500	"	"

<sup>1</sup> In all experiments the carbonate content of the soil was estimated and sufficient 2% HCl of sp. gr. 1.15 added to leave an excess of acid.



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### HYDROCHLORIC ACID METHOD OF DISCRIMINATING BETWEEN CYSTS AND ACTIVE FORMS.

The control experiments described above show that the hydrochloric acid method is capable of giving approximately accurate counts of the active protozoa of the soil. The method now in use in this laboratory is as follows.

On one part of the soil sample total protozoal counts are made by the dilution method described below. Another sample—10 grams of soil—is then treated with sufficient 2 per cent. HCl (see p. 139, footnote) to neutralise the carbonate present and still leave an excess of unchanged 2 per cent. acid. The acid is allowed to act overnight. After treatment the number of protozoa in the sample is ascertained by the dilution method; this gives the number of cysts since the acid has killed all the active forms, leaving most of the cysts unharmed. The number of cysts subtracted from the total number of organisms given by the first count gives the number of active protozoa per gram of the soil sample<sup>1</sup>.

The details of the dilution method, devised by Cunningham, modified by L. M. Crump, and used in my laboratory, are as follows:

10 grams of soil are passed through a 3 mm. sieve and then added to 100 c.c. of sterile tap water or physiological salt solution. This gives a 1/10 dilution. From it further dilutions are made as shown below.

No. 1.	10 gm. soil	in 100 c.c. H <sub>2</sub> O	= 1/10	dilution
„ 2.	10 c.c. No. 1 „	90 „	„	= 1/100 „
„ 3.	5 „ „ 2 „	45 „	„	= 1/1000 „
„ 4.	20 „ „ 3 „	30 „	„	= 1/2500 „
„ 5.	20 „ „ 4 „	20 „	„	= 1/5000 „
„ 6.	30 „ „ 5 „	15 „	„	= 1/7500 „
„ 7.	30 „ „ 6 „	10 „	„	= 1/10,000 „
„ 8.	20 „ „ 7 „	30 „	„	= 1/25,000 „
„ 9.	20 „ „ 8 „	20 „	„	= 1/50,000 „
„ 10.	30 „ „ 9 „	15 „	„	= 1/75,000 „
„ 11.	30 „ „ 10 „	10 „	„	= 1/100,000 „

Nutrient agar is poured into sterile Petri dishes. When the medium has solidified, the dishes are inoculated in pairs with 1 c.c. of each dilution. Incubation at 20° C. is continued for 28 days, and the plates examined at intervals of 7 days, 14 days, 21 days and 28 days. This long period of incubation is necessary in order to ensure accurate results.

<sup>1</sup> As further controls after treatment the titration value of the acid solution over the soil is estimated and the fluid allowed to act on a culture of active protozoa in order to prove that the acidity is sufficient to cause the death of all active forms.

The hydrochloric acid method has been in use for a short time only, but sufficiently long to show that it gives concordant and apparently accurate results.

A few of these are given in Table III.

Table III.

Date sample taken	Manurial treatment of plot	Number of protozoa per gm. (cystic and active)			Number of active protozoa per gm.			Water content
		A*	F	C	A	F	C	
July 29, 1919	Farmyard manure	1000	25,000	100	900	17,500	90	17.52
	Unmanured	2500	2500	0	2400	1500	0	14.07
Aug. 18, 1919	Farmyard manure	100	1000	10	90	900	10	3.08†
	Unmanured	100	5000	10	90	4900	10	4.81
Oct. 8, 1919	Farmyard manure	2500	25,000	10	0	17,500	10	15.48
	Unmanured	7500	7500	0	2500	5000	0	13.24
Oct. 27, 1919	Farmyard manure	2500	5000	10	1500	4000	0	19.11
	Unmanured	100	1000	0	90	950	0	12.87
Nov. 13, 1919	Farmyard manure	500	2500	10	400	0	0	22.27
	Unmanured	100	100	0	50	0	0	16.17

\* In the above table A = amoebae; F = flagellates; C = ciliates.

† This value is remarkably low; the sample was taken after a long period of drought.

The experimental plots investigated are part of Broadbalk field where wheat has been grown continuously since 1843. One of the plots has received no manure since 1843; while the other has had applied to it 14 tons per acre of farmyard manure yearly since 1852.

#### DISCUSSION.

Table III demonstrated that in the soils investigated there are normally present a number of active trophic protozoa, even when the moisture content of the soil reaches the unusually low proportion of 3.08 per cent. or 4.81 per cent.

As shown in a previous paper(4) it is probable that protozoa are usually resident on the soil particles, from which it seems to follow that the organisms are in a moist environment even when the soil is low in water content.

The hydrochloric acid method has not been in operation sufficiently long to allow of discussion upon the proportion of active to cystic protozoa, which apparently varies from month to month; nor of the action of external factors upon the ratio. It is obvious, however, that interesting results will follow the application of the method over a long period.

In Tables I and II it will be noted that the number of protozoa recovered after treatment with the acid is in most cases somewhat less than

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was expected. On no occasion were more recovered. This may be due to two causes—experimental error, and death of certain cysts. Experimental error will doubtless explain a certain amount of discrepancy, but the whole cannot be ascribed to this cause, for on such an assumption one would expect the numbers to be both greater and less than expectation, and not only in one direction.

Certain cysts, however, will probably be killed by the hydrochloric acid, thus giving a uniformly lower count after treatment than before it. Protozoa at the beginning of encystation, or in the last stage of excystation are much less resistant to the action of acid and would probably be killed by such treatment. As these processes are continually going on in the soil a certain proportion of cystic protozoa will therefore be killed by the hydrochloric method. Nevertheless the error so produced is not a serious one, for organisms in such conditions would in the one case be active a short time before the soil sample was taken, and in the other case would become active immediately afterwards. These cysts therefore could be regarded as active forms. Finally, it must be remembered that the word cystic is used for two quite distinct conditions—a point most soil protozoologists seem to have ignored. Physiologically there are two types of cysts—the reproductive and the resistant (“dauerzysten”). Our knowledge of the reproductive cysts of soil protozoa is extremely scanty, both as regards the species which produce them and as to their resistance to unfavourable external conditions. It may well be that treatment with hydrochloric acid kills some or all of such cysts. However, a thorough investigation of these questions is in hand. Notwithstanding these possible sources of error, the hydrochloric acid method gives sufficiently accurate results to warrant its application to the counting of active soil protozoa<sup>1</sup>.

### SUMMARY.

1. A method is described by which it is possible to estimate the numbers of active protozoa in a soil.
2. The total number of protozoa is first found by a dilution method. A fresh portion of the soil is then treated with 2 per cent. HCl (sp. gr. 1.15) overnight. By this means all active forms are killed. A second count by the dilution method gives the number of cystic protozoa in the soil. From these results the number of active forms can be ascertained.

<sup>1</sup> While this paper has been passing through the press Collett has published an interesting account of the toxicity of acids to ciliates (*Journ. Exp. Zool.* **29**, p. 443, 1919).

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ON THE CHANGES THROUGH WHICH THE NODULE  
ORGANISM (*PS. RADICICOLA*) PASSES UNDER  
CULTURAL CONDITIONS.

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(With Plates I-III and One text-figure.)

SINCE Hellriegel and Willfarth's discovery in 1888 of the peculiar nitrogen nutrition of leguminous plants by symbiosis with specific micro-organisms, and the further work on the isolation of the organisms and the mode of infection of the plant by Beijerinck and Prazmowski respectively, a considerable number of investigations have been made on the nodule organism and its relation to the host plant. The earlier studies included many observations on the morphology of the organism, but the realisation of the possibility of soil inoculation and its practical significance naturally directed attention largely to the development of cultural technique and no corresponding advances were made in our knowledge of the mechanism of the process of nitrogen fixation, or of the development of the organism itself. The work of Nobbe and Hiltner, Simon, Harrison and Barlow, and Kellerman has placed the preparation and use of virulent cultures on a definite basis. But as regards the morphological side we are still unable to reproduce, *in vitro*, the characteristic changes through which the organism is known to pass in symbiosis with the plant, nor has much light been thrown on the chemical processes in the nodule. Quite recently Burrill and Hansen (1) have pointed out that the life-cycle from the soil to the nodule and back to the soil is unknown and that we have as yet no clue as to the form in which the organism exists in the soil.

The early investigations of Beijerinck (2) led him to recognise the existence of three stages through which the organism passes prior to and during its period of existence with the host plant. The first of these is the swarmer stage in which form actual infection of the plant takes place. The cells are actively motile and of extremely small dimensions,  $0.9\mu$  long and  $0.18\mu$  broad, and on this account were regarded by

Beijerinck as representatives of the smallest living organisms. Subsequent to the infection of the plant, the swarmer gradually assumes a larger asymmetrical spindle-shaped rod form, about  $4\mu$  long and  $1\mu$  wide, which eventually develops into the characteristic branched individuals, the so-called bacteroids. Although Prazmowski<sup>(3)</sup> employed, in part at least, media of the same composition as those used by Beijerinck, the dimensions of the organisms encountered in pure culture differed. Prazmowski mentions, in addition to infinitely small cells, the occurrence of larger motile bacilli,  $2\mu$ – $3\mu$  long and  $0.2\mu$  wide, which are often to be found as chains of two, three, or four cells.

Gonnermann<sup>(4)</sup> employed plant-extract peptone gelatine, and claimed by the use of this medium to have isolated ten different nodule bacteria, seven of which passed as *Bacilli tuberigeni*, two as *Micrococci tuberigeni* and the other was identified as *Bacillus fluorescens non-liquefaciens*. In view of the peculiar conditions under which he obtained these organisms, and the absence of any of the precautions which are now considered to be necessary for the isolation of the nodule organism, it is difficult to attach any importance to his results. Mazé<sup>(5)</sup> regarded the organism as being markedly pleomorphic and mentions a fact worthy of note in connexion with our own results, namely, the tendency of the organism, when grown in an atmosphere of nitrogen, to assume a coccus form which, on subsequent cultivation under aerobic conditions and especially on potato, gave rise to bacilli again.

Although the predominant forms usually found in pure cultures of the nodule organism are those first described by Beijerinck, the occurrence of more complex cells such as bacteroids of the normal nodule has frequently been noted; in fact, definite attempts have been made to induce bacteroid formation on artificial media. Beijerinck<sup>(6)</sup> first mentioned their presence in pure cultures, and at a later date Stutzer<sup>(7)</sup> and Hiltner<sup>(8)</sup> carried out a considerable number of experiments with different media with the object of securing extensive bacteroid formation. While it was possible to obtain isolated cases of the formation of much branched cells in certain of these media, the experiments were only partially successful, the branched forms being relatively few in number and varying both in size and shape from those ordinarily found in the nodule. On the other hand, little attention has been paid to the reverse change of the organism, i.e. the "down-grade" transition from the more complex to the simpler forms. In the main, observations have been confined to the dissolution of the bacteroid forms obtained from living nodules, and Prazmowski<sup>(3)</sup> gives illustrations of the degeneration of

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bacteroids into "oily" globules. Morek<sup>(10)</sup>, although failing to realise the true nature of the bacteroid form, which he regarded as a product of the plant itself, recorded the presence in the bacteroid of a "micrococcus-like microbe."

Löhnis and Smith<sup>(11)</sup> studied the forms produced by *Ps. radiculicola* and noted the presence of small globules and ovals, slime threads and cocci, regenerative bodies, and observed the granular decomposition of small rods and threads to form "spores."

### THE PRESENT INVESTIGATION.

In the course of an investigation having for its object the production of active and virulent cultures of the organism, a number of nutrient media were prepared in the hope that a satisfactory substitute for the ash-maltose agar of Harrison and Barlow<sup>(12)</sup> might be obtained, since much appears to depend on the preparation of the plant ash used for this purpose. Cultures of the nodule organism were isolated from red clover, broad bean, lucerne and lupine plants and transferred weekly to a range of fresh media. It was noticed, however, during the microscopical examination of these cultures prior to transference, that certain of the tubes contained a number of coccoid forms scattered among the normal rod vegetation of the cultures. Especially was this the case in cultures of the red clover organism.

It was at first thought that these coccoid forms might represent a definite infection and our attention was consequently directed to their elimination by repeated sub-cultures. The Petri dish cultures gave rise to one type of colony only and, after transference of several of these to slant culture tubes, the growths were again replated and again tubed. This was repeated six times, and in none of the cultures was it possible to detect the coccoid forms upon examination after seven days. Finally the organism was tested for specificity by infection of clover seedlings. To this end, clover seeds were sterilised in mercuric chloride solution and, after being washed in sterile water, were transferred to sterile water agar in Petri dishes to germinate. After five days six sterile seedlings were transferred to Erlenmeyer flasks containing sterile mannite mineral salt agar and inoculated with a culture obtained in the above manner. At the end of one month the seedlings possessed from four to seven nodules each and thus satisfactorily demonstrated the conformity to type of the cultures employed. Furthermore, the cultures used for these infection experiments were again induced to give rise to the coccoid forms by the methods described below.

The observations recorded in this paper show that the life-cycle proceeds in the following five stages:

(1) *The pre-swarmers form (non-motile)*. When a culture of the organism is placed in a neutral soil solution, it is converted after four or five days into the pre-swarmers form (see Fig. 1.1).



Fig. 1. 1. Pre-swarmers first stage. 2. Pre-swarmers second stage. 3. Swarmer. 4. Motile rod. 5. Highly vacuolated rods.

(2) *Second stage, larger non-motile coccus*. When the pre-swarmers are transferred to a suitable medium, such as mannite agar, they undergo a change. The original coccoid pre-swarmers increases in size until its diameter has been doubled, but still remains a non-motile coccus.

(3) *Swarmer stage, motile*. The cell then becomes ellipsoidal and develops high motility. This form is the well-known "swarmer" of Beijerinck.

(4) *Rod-form*. Proceeding in an "up-grade" direction, the swarmer becomes elongated and gives rise to a rod-form, which is still motile, but decreasingly so. So long as there is sufficient available carbohydrate in the medium, the organism remains in this form.



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(5) *Stage of high vacuolation.* When however the organism is placed in a neutral soil extract (or the available carbohydrate becomes exhausted), it becomes highly vacuolated and the chromatin divides into a number of bands. Finally these bands become rounded off and escape from the rod as the coccoid pre-swarmers, 1.

Our experiments show that lack of available carbohydrates is conducive to pre-swarmers formation, while in the presence of available carbohydrates the pre-swarmers become swarmers and finally rods.

### EXPERIMENTAL

In general the media used for the cultivation of the nodule organism consisted of two solutions, soil extract and mineral salt solution, from which five stock agar media were prepared. The soil extract was made by steaming one kilo of garden soil with two litres of distilled water for a period of two hours, after which the liquid was filtered through a Berkefeld filter candle. The mineral salt solution was that suggested by Ashby(13) and consisted of:

Magnesium sulphate	...	...	0.2 gm.
Sodium chloride	...	...	0.2 "
Mono-potass. phosphate	...	...	0.2 "
Calcium sulphate	...	...	0.1 "
Calcium carbonate	...	...	0.2 "
Water (dist.)	...	...	1000 c.c.

The composition of the different agar media is set out below:

	Soil Extract Agar	Soil Extract Mannite Agar	Soil Extract Saccharose Agar	Mannite Agar	Saccharose Agar
Soil Extract (c.c.)	1000	1000	1000	—	—
Mineral Salt Soln (c.c.)	—	—	—	1000	1000
Mannite (grms.)	—	10	—	10	—
Saccharose (grms.)	—	—	10	—	10
Agar (grms.)	15	15	15	15	15
Reaction	0°	-1.5°	-1.5°	-1.5°	-1.5°

During the course of repeated cultivations of the nodule organism on these media and especially in those cases when recourse was had to the use of soil extract media, the occurrence of coccoid bodies was noted. On the one hand, frequent transferences and repeated preparation

of plate cultures sufficed to demonstrate the purity of the cultures, which had thus given rise to divergent forms and, on the other, the final tests on the plant infection power were carried out on the lines already indicated. The identity of the organisms having thus been definitely established, it was decided to ascertain as far as possible the conditions that made for the occurrence of these coccoid or pre-swanner forms.

In the main we have studied the conditions of aeration and food supply and the effect of various temperatures on the growth of the organism.

#### RELATIONS TO AIR SUPPLY.

Since the conditions in liquid media and in masses of actively growing bacteria might reasonably be expected to be only partially aerobic, a considerable number of observations have been made on the behaviour of the nodule organism when exposed to an anaerobic environment. Preliminary experiments included the use of the specific organism from red clover, broad bean, lucerne and lupin, the cultures being made on soil extract mannite agar, either in tubes or flasks. For convenience of operation the tubes were placed in a glass bottle with a supply of alkaline pyrogallol. After the necessary inoculation had been carried out, the flasks or bottles were evacuated by attachment to the pump, and normal pressure was then restored by allowing a slow current of air to pass through a vessel containing a deep layer of alkaline pyrogallol. This alternate evacuation and replacement by an oxygen-free atmosphere was repeated ten times and the cultures were then incubated. While the clover and lucerne organisms failed to grow under these conditions, those of broad bean and lupin after fourteen days covered the surface of the agar as a slightly mucilaginous mass. Further incubation under these conditions led to a decrease of mucilage and subsequent examination revealed the presence of the coccoid forms to which reference has already been made.

To test the effect of anaerobic conditions on the clover and lucerne organisms, a number of cultures were set up and submitted to preliminary incubation for seven days with free access of air. When growth of the organisms was sufficiently far advanced, the tubes were transferred to anaerobic conditions and observations were subsequently made at definite periods. Once a culture had been opened and examined it was discarded, the possible disturbance from intermittent aerobic conditions being thus avoided.

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### HISTORY OF ORIGINAL CULTURES.

All the cultures were derived from strains isolated four months previously with the observance of the precautions set out by Harrison and Barlow (12). During this period they were repeatedly cultivated on soil extract mannite agar, and by means of transference once a week the organisms were maintained in the form of actively motile small rods. After certain periods under anaerobic conditions the following observations were recorded:

- 2 Days. *Bean and lucerne cultures*—thick, mucilaginous rod forms.  
*Clover*—non-mucilaginous and increased vacuolation of cells.  
*Lupin*—decrease in mucilage; increased vacuolation; rapid division to small rods in some cases.
- 3 Days. *Bean*—mostly rod form; very mucilaginous; some rods highly vacuolated.  
*Lucerne*—small highly vacuolated rods.  
*Clover*—small rods; increase in vacuolation.  
*Lupin*—small and large vacuolated rods.
- 7 Days. All highly vacuolated. Plate II, fig. 3.
- 9 Days. Cocci appearing in clover culture. Plate II, fig. 4.
- 19 Days. Cocci appearing in all cultures.
- One Month. Many cocci in all cultures.

After 19 days one set of tubes was removed from anaerobic conditions, sterile air was passed through the vessel and the cultures were then incubated.

- 2 Days. Number of cocci increased.
- 4 Days. Appearance of small rods.
- 12 Days. Mostly all rods; little or no vacuolation.

In continuation of these experiments the effect of other atmospheres on the growth of the organism has also been determined. While cultivation in oxygen leads to the production of good mucilaginous growth and of forms showing high differentiation of the cell contents (Plate II, fig. 1), confinement in an atmosphere of hydrogen results in a reduction of the mucilaginous character and an abundant formation of the pre-swarm stage. Exposure to the action of free ammonia in normal atmosphere reacts unfavourably on growth of the organism and tends to the production of capsules. Coal gas is equally unsuitable—the cells become capsulated, while branched forms are frequent.

It is thus seen that any deviation from strictly aerobic conditions exercises a prejudicial effect on the growth of the organism, but the

extent to which these changes proceed appears to be determined by other conditions, such as, for example, those of nutrition. Under comparable aerobic conditions, cultivation on soil extract mannite agar and on soil extract saccharose agar induced a free formation of pre-swarmers, but this occurred to a much less degree on similar media without soil extract; soil extract agar without additional source of carbon gave rise solely to small rods.

#### THE PRODUCTION OF THE PRE-SWARMER STAGE FROM ROD STAGE.

In our original cultures grown on soil extract mannite agar and transferred weekly to fresh medium, the organism exists mainly as a short actively motile rod 3-4 $\mu$  long and 1 $\mu$  broad. Increase of age of culture is accompanied by decrease in motility and a marked production of mucilage. The cells no longer take the stain uniformly and densely, but exhibit a definite banding of their contents. [Plate II, figs 3, 5. Plate III, figs. 1, 2, 3, 5.] Soil extract media appear to be especially potent in rapidly inducing these effects.

Under restricted conditions of aeration the vacuolation increases until the chromatin substance has become segregated to small particles scattered along the cell. In branched forms the particles are seen at the angles and extremities of the arms as well as along the rod. Occasionally the cells appear to be regularly banded but at other times the change only gives rise to a reticulate effect. This condition has been previously observed by other workers, and Miss Dawson(11) asserted that these chromidial particles were simply due to vacuolation and showed no analogy with spore formation.

In a few instances the formation of chromatin patches and bands has followed a definite sequence of division, but usually there is a little evidence of a dominant phase. In one case, for example, the initial material consisted wholly of uniformly staining rods. At the end of one hour stained films from this culture showed a predominance of cells possessing an achromatic patch distant about one-third of the length of the cell from one end. A few minutes later this patch had extended as a band across the cell and half an hour later the larger chromatin particle had also divided, producing three equal granules in the cell. Two hours later each of these had again divided, thus producing six chromatin bands placed at regular intervals across the rod. As already indicated above no such definite subdivision is as a rule perceptible, and the chromatin cell contents break up into particles of equal size. In small rods the chromatin may be grouped as a central band or as

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two polar bands, while still larger rods may possess as many as fourteen densely staining bands. Swollen globular forms have been found to exhibit a reticulate segregation with a number of chromatin granules scattered about the periphery of the cell (Plate III, fig. 6). Subsequent changes appear to proceed in either of two ways. At times the chromatin particles become definitely organised cocci within the rod (Plate II, fig. 3), but usually they remain as bands and only the terminal granules become coccoid. The cell wall may dissolve as a whole, leaving a string of "pre-swarmers" having the appearance of streptococci, or it may dissolve locally, similarly permitting of the emergence of a "pre-swarmers." Hence pre-swarmers are found to occur as masses, chains or singly. They are non-motile, and stain readily and densely with carbol fuchsin and gentian violet, Loeffler's methylene blue, and with Heidenhain's haematoxylin. At the moment of liberation they do not appear sufficiently well-defined to suggest the possession of a cell wall, nor do they show the characteristic behaviour of spores towards the usual stains.

The original pre-swarmers are small ( $0.4\mu$  diameter) and stain densely. Under favourable conditions it swells to about twice its original diameter; it then stains less densely, and finally becomes a swarmer of high motility. From this time, and with continued incubation, the usual transition through small rods, long rods, to ultimate pre-swarmers formation may be induced. The production of pre-swarmers is not limited to normal rods. We have observed branching bacteroids and large involution forms passing through the same changes and eventually giving rise to pre-swarmers.

With the object of ascertaining the relation of these changes to the normal process of development and disintegration in the nodule, a number of observations have been made on the contents of old bean nodules, immediately prior to dissolution. They were invariably black and pulpy within, but only those nodules were used whose outer walls were intact. Examination of the bacterial slime within the nodule showed most organisms to exist as the frequently observed, highly swollen, branched and vacuolated "ghost" form (Plate I, fig. 1). Dense masses of chromatin were found within the cells, sometimes as transverse bands and at others as a lining to the periphery. The chromatin masses break down into pieces of varying size and shape, some having the coccus form resembling pre-swarmers, while densely staining bacilli were also found.

In the old nodule of red clover, the "ghost" form is smaller than that of the bean, but much of the chromatin leaves the bacteroid in the pre-swarmers form.

There is thus some indication that the formation of pre-swarmers is a normal course and is not primarily determined, although it may be markedly influenced, by cultural conditions.

#### THE INFLUENCE OF SOIL CONDITIONS ON PRE-SWARMER FORMATION.

In view of the pronounced tendency to the formation of pre-swarmers in soil extract media, a number of observations have been made to ascertain whether this effect was a positive one, i.e. due to the presence of some definite substance or group of substances, or merely negative, as the result of a deficiency of nutrient materials. To this end, a number of young vigorous cultures of red clover, broad bean, lupin and lucerne organisms were taken, all of which showed the bacteria in the normal rod form. Soil extracts were prepared by digesting 30 parts of soil with 100 parts of distilled water, (a) in the cold, (b) by steaming for one half-hour and (c) by heating in the autoclave at 25 lbs. pressure for the same period. After this period of digestion, the respective extracts were filtered by passage through a Doulton filter candle, placed in separate portions of 100 c.c. in Erlenmeyer flasks and sterilised in the autoclave. Two controls were introduced, one with distilled water and the other being a flask with 30 grms. soil and 100 c.c. water autoclaved, but not filtered. In all cases quantities of about 10 c.c. of the respective liquids were transferred to strong agar slant cultures, the bacterial mass scraped off by means of a sterile platinum needle and the bacterial suspension then returned to the flask.

Examination after various periods gave the following results:

Medium	After 18 hours	After 5 days	After 19 days
Distilled water	Pre-swarmers appear in clover cultures	10% pre-swarmers in clover, bean and lupin. Few in lucerne	Number of organisms greatly reduced
Cold Soil Extract	"	25% pre-swarmers in all cultures	"
Extract of Steamed Soil	Pre-swarmers appear in clover and lupin cultures	50% pre-swarmers in all cultures	"
Extract of Autoclaved Soil	Pre-swarmers appear in clover cultures	Clover practically all pre-swarmers. Bean, some pre-swarmers. Lucerne mostly small rods	Clover and lupin all pre-swarmers. Bean and lucerne about 50%
30 grms. Soil, 100 c.c. Water	Pre-swarmers appear in clover, bean and lucerne. Lupin showed rapid division of long rods	"	"

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Transference of an active culture to soil extracts prepared in various ways, or to distilled water, thus rapidly leads to pre-swarmer formation, and this uniformity of result in itself suggests that this effect is due more to deficiency of food substances than to the presence of any substance formed by the action of high temperatures on the soil. This is rendered more probable by the following experiments.

(1) *The addition of cultures to non-sterile soil.* In this case mass inoculation of non-sterile soil was carried out, the bacterial suspension being of such a strength that the nodule organism predominated over the other soil organisms and could be readily picked out in film preparations.

After four days films were obtained which showed the nodule organisms in excess of the other soil forms. All the cells were producing pre-swarmers in large numbers.

(2) *The effect of a cold soil extract on the organism.* Since the soil extract prepared in series (1) was necessarily of a much lower concentration than the soil water, we attempted to prepare an extract of more normal strength. In the absence of facilities for the preparation of extracts by combined pressure and displacement methods, an extract made in the ordinary manner, by digesting 500 grms. soil with 400 c.c. of distilled water for 18 hours and filtered through a Doulton candle, was concentrated *in vacuo* at 40° under aseptic conditions to one-fifth of its volume, i.e. to the volume of water originally contained in the soil. A culture of the organism was then added to the concentrated extract and incubated at 30°. Observations made at regular intervals of 12 hours showed a gradual but definite increase of pre-swarmer forms from the seventh to the ninety-sixth hour, by which time they formed practically the whole of the population. After six days a quantity of 1.0 per cent. sterile saccharose solution was added to the culture, and resulted in the transformation of the organism from the pre-swarmer to the rod form. These ultimately gave rise to the pre-swarmers and were again transformed to rods on the addition of more saccharose. It is, therefore, evident that pre-swarmer formation may be attributed among other causes to lack of food material. We have, however, a certain number of indications not only that lack of air supply tends to make for pre-swarmer formation in otherwise suitable media (p. 151), but that free aeration exercises the reverse effect, i.e. it appears to promote swarmer formation in otherwise unsuitable solutions.

The possible effect of previous environment on the liability to pre-swarmer formation has been tested by growing strains of the nodule

organism, previously cultivated on a range of different media, in a soil extract known to favour the production of pre-swarmers. Cultures derived from soil extract agar, saccharose agar, mannite agar, and soil extract mannite agar, were each transferred to soil extract; after 20 days all cultures gave rise to extensive pre-swarmers formation.

#### THE RELATION OF TEMPERATURE TO PRE-SWARMER FORMATION.

Comparative observations have been made to ascertain how far pre-swarmers formation or, on the other hand, persistence of the rod form, is affected by temperature. For this purpose eight flasks, each containing 30 grms. of field soil and 100 c.c. of distilled water, were sterilised in the autoclave and, after inoculation, were incubated at different temperatures, viz. 37°, 30°, 25°, and at room temperature. After 20 days the cultures showed:

- At 37°—large dense rods with few pre-swarmers.
- „ 30°—smaller dense rods; number of pre-swarmers greater than at 37°.
- „ 25°—pre-swarmers dominant.
- „ room temperature—pre-swarmers dominant.

#### THE INFLUENCE OF CERTAIN SOIL CONDITIONS ON THE PRODUCTION OF PRE-SWARMERS.

In addition to the foregoing results which were obtained by the use of Rothamsted garden soil, some further information has been derived from an examination of the behaviour of the organism towards a number of other soil types. The general method adopted was to sterilise 30 grms. of the soil with 100 c.c. of distilled water in a 250 c.c. Erlenmeyer flask. Sterile distilled water (5 c.c.) was added to a tube culture of the organism, the growth brought into suspension with a platinum needle, and then transferred to the flask. The whole was incubated at 30° and observations made at intervals.

Without entering into a detailed account of the various results, it may suffice to state that the type of soil and particularly the presence or absence of available base appears to exercise a profound effect on the form of cell arising under otherwise identical conditions. Definitely acid soils lead to the production of involution forms and finally to the extinction of the organism. This, of course, is strictly in accordance with the known intolerance of the nodule organism of acid conditions.



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Soils with an excess—either small or large—of calcium carbonate readily induce the formation of the pre-swarmers from normal rods, and this change can also be effected by the addition of calcium or magnesium carbonate to acid soils which would normally lead to the production of involution forms.

An interesting case was presented by a light sandy loam from Woking, the reaction of which was slightly alkaline to litmus. On the addition of a normal culture to this soil, the organisms persisted in the form of small and large densely staining rods, whilst no pre-swarmers were to be observed. In this case also the addition of calcium or magnesium carbonate resulted in the conversion of 95 per cent. of the cells into the pre-swarmers stage within the period of seven days. The great uniformity with which this change may be induced rather suggests the existence of the nodule organism in the pre-swarmers form in normal soils.

An extension of these observations, on the effect of soil conditions on the predominance of a particular form of the organism, led to an examination of a number of soils from the permanent barley plots on Hoos Field. The treatment of the different plots includes, as is well known, a range of mineral manures with and without the addition of nitrogen in the form of sodium nitrate and of ammonium sulphate, while one plot receives a dressing of farmyard manure annually in spring. The results of these experiments show in the majority of cases a definite tendency of the organism towards pre-swarmers formation after a period of 14 days, but in the case of the unmanured soil, peculiarly enough, the organism remained in the rod form.

### CONVERSION OF PRE-SWARMERS INTO SWARMERS.

In the following two series of tests we attempted to convert the pre-swarmers into the swarmers, in contradistinction to the earlier experiments, where attention was specially paid to the converse change. It was necessary, therefore, to induce the pre-swarmers stage before any of the test substances were supplied. This was done by previous cultivation in sterilised garden soil and distilled water containing 1.0 per cent. calcium carbonate, and when about 95 per cent. of the organisms were in the pre-swarmers stage, the compounds were added as sterile solutions.

Subsequent observations showed the following:

Compound added to control	Form of organism	
	After 1 day	After 7 days
Control (soil extract) ... ..	Pre-swarmers dominant	Pre-swarmers dominant
0.1% Sodium nitrate ... ..	"	"
" Calcium nitrate ... ..	"	"
" Ammonium sulphate ... ..	"	"
" Asparagin ... ..	"	"
" Peptone ... ..	"	"
" Sodium chloride ... ..	"	"
" Potassium sulphate ... ..	"	"
" Calcium sulphate ... ..	"	"
" Magnesium sulphate ... ..	"	"
" Manganese sulphate ... ..	"	"
" Ferric chloride* ... ..	"	"
" Di-potassium phosphate ... ..	"	Few swarmers, Pre-swarmers dominant
" Mono-potassium phosphate ... ..	"	Increase of swarmers, Pre-swarmers dominant
" Calcium phosphate ... ..	Small rods (dense)	Small rods (dense)

\* This substance allows of only a poor growth of the organism.

The addition of all the inorganic and organic sources of nitrogen and of the majority of the mineral salts is thus shown to be ineffective as a means of inducing the production of swarmers. The phosphates behave differently, however, and the effect of calcium phosphate, although at present inexplicable, might possibly constitute a secondary factor in the known response of leguminous crops to phosphatic manures.

The second series consisted in a similar comparison of the values of a number of higher alcohols and sugars, all of which were supplied in a concentration of 0.01 per cent. For convenience of comparison the compounds have been arranged in two groups according to their value for bringing about the desired change of the pre-swarmers to the swarmer. Furthermore, it should be borne in mind that three grades of action are possible. In the first, particularly suitable compounds rapidly induce the production of swarmers and later of normal rods, but with exhaustion of the carbon source there occurs a correspondingly early passage to the pre-swarmers stage. The second is that effected by less suitable compounds which, within a prescribed period, only slowly converts the pre-swarmers to swarmers and rods. The third grade gives purely negative results; it is seen when the compound is unsuitable for the growth of the organism. The results are given in the following table:

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Compound tested	Form of organism		
	Initial stage	After 4 days	After 28 days
Ammonium tartrate	Pre-swarmer	Rods; swarmer dominant	Pre-swarmer dominant
Mannite ... ..	"	Swarmer dominant	Small rods dominant
Maltose ... ..	"	Swarmer and rods	Pre-swarmer
Lactose ... ..	"	"	"
Dextrose ... ..	"	Small rods	"
Raffinose ... ..	"	"	Pre-swarmer dominant
Saccharose ... ..	"	Dense rods	All pre-swarmer
Glycerine ... ..	"	Pre-swarmer dominant	Small rods dominant
Laeulose ... ..	"	"	Swarmer dominant
Galactose ... ..	"	"	"
Arabinose ... ..	"	"	Pre-swarmer dominant
Starch ... ..	"	"	"
Inulin ... ..	"	"	"
Dextrose ... ..	"	"	"

The determining influence of carbohydrate supply on the form assumed by the organism is well illustrated by an experiment in which successive small doses of saccharose were supplied to a culture of the organism. In this manner it was possible to convert a pre-swarmer vegetation to one of dense rods and, from the alternate supply and exhaustion of the sugars, the numbers of either form could be well represented by an asymptotic curve.

It has already been shown that the addition of calcium carbonate to a soil containing the organism in the rod form, leads to a conversion to the pre-swarmer stage. This is likewise the case when excess of calcium carbonate is added to a saccharose medium containing the organism in the swarmer stage:

(1)	Soil flask	...	0.1% Saccharose	...	{ dense rods
(2)	"	...	{ 0.1% Saccharose 0.01% CaCO <sub>3</sub>	...	{ dense rods
(3)	"	...	{ 0.1% Saccharose 0.1% CaCO <sub>3</sub>	...	{ highly vacuolated rods producing pre-swarmer.
(4)	"	...	{ 0.1% Saccharose 0.5% CaCO <sub>3</sub>	...	{ many free pre-swarmer; greater vacuolation of rods.

These experiments demonstrate that the following factors influence the formation of the pre-swarmer stage:

- (1) Lack of available organic food material.
- (2) The presence of excess of calcium carbonate.

## SOIL CONDITIONS FAVOURABLE TO THE CONVERSION OF PRE-SWARMERS TO SWARMERS.

The conversion of pre-swarmers into swarmers is effected not only by the pure substances referred to in the above tables, but by other substances commonly present in the soil. It is facilitated by horse manure, straw and plant residues. Aqueous extracts were used in all cases and, as before, the organisms were initially in the pre-swarmers stage. The results are given in the following table:

Substance tested	Form of organism		
	After 2 days	After 7 days	After 28 days
Horse manure extract	All rods	All rods	Some pre-swarmers present
Straw extract	Rods dominant	Rods dominant	Some pre-swarmers present
Horse faeces extract	A few rods present	Pre-swarmers dominant	Pre-swarmers dominant
Bean root extract	Rods dominant	Rods dominant	Rods dominant
Clover root extract	"	"	"
Lucerne root extract	"	"	"
Vetch root extract	"	Pre-swarmers dominant	Pre-swarmers dominant

Thus it appears that certain, if slight, differences exist in the nutritive value of the various extracts tested. Those prepared from the legume roots bring about a continued growth of the organism in the rod form; dung and straw extracts are less effective in this direction, whilst horse faeces extract is almost without action.

The up-grade and down-grade changes in the form of the nodule organism deserve attention on account of their bearing on field problems. Excess of calcium or magnesium carbonates in the soil makes for rapid pre-swarmers production and consequently provides the best starting point for a strong growth of cells capable of infecting the host plant. The effect of phosphates in converting pre-swarmers into swarmers might also be expected to facilitate infection. The importance of a proper supply of phosphates for the growth of leguminous crops is well recognised and may be due, in part, to some biological change to which it gives rise. On the other hand, there has been some difficulty, in the past, in reconciling theoretical conceptions of the necessary manurial treatment of leguminous crops with agricultural practice, since the application of farmyard manure has long been, and still is, believed to be of great value in the cultivation of legumes (E. J. Russell<sup>(15)</sup>). The results obtained in our experiments provide an explanation that

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would quite well meet such cases. Finally, a considerable amount of experimental work has consisted in a comparison of the relative value of inoculating by means of pure cultures, as against that by means of soil. The general results obtained in this direction have almost invariably shown the superiority of the latter method. Although this is, no doubt, due in part to the lack of virulence in some of the cultures used, some of the effect might well be attributed to the form in which the organism was presented to the plant. Our investigations show that soil is instrumental in the formation of the pre-swarmer form, and this form might well be expected to make for an earlier or more effective infection of the plant. Investigations on the relative efficiency of the different forms in infecting the plant are still in progress.

### SUMMARY.

It is shown in the preceding pages that under certain cultural conditions the nodule organism from the roots of red clover, broad bean, lucerne and lupin exhibits a tendency towards granular disintegration of the cell with the formation of small non-motile coccoid bodies, about  $0.4\mu$  diameter.

In the cultures ordinarily in use these coccoid bodies are not formed extensively, but cultivation on soil extract media rapidly leads to their production, until finally they constitute the predominant type in the culture.

A life-cycle consisting of five stages is described:

(1) *The pre-swarmer form (non-motile)*. When a culture of the organism is placed in a neutral soil solution, it is converted after four or five days into the pre-swarmer form.

(2) *Second stage, larger non-motile coccus*. In presence of saccharose, certain other carbohydrates, and phosphates, etc., the pre-swarmer undergo a change. The original coccoid pre-swarmer increases in size until its diameter has been doubled, but still remains a non-motile coccus.

(3) *Swarmer stage, motile*. The cell then becomes ellipsoidal and develops high motility. This form is the well-known "swarmer" of Beijerinck.

(4) *Rod-form*. Proceeding in an "up-grade" direction, the swarmer becomes elongated and gives rise to a rod-form, which is still motile but decreasingly so. So long as there is sufficient available carbohydrate in the medium, the organism remains in this form.

(5) *Vacuolated stage*. When, however, the organism is placed in a neutral soil extract or the available carbohydrate becomes exhausted, it becomes highly vacuolated and the chromatin divides into a number of bands. Finally these bands become rounded off and escape from the rod as the coccoid pre-swarmers, 1 (see Fig. 1).

The formation of the coccoid bodies (pre-swarmers) may also be induced by the addition of calcium or magnesium carbonates to the medium or by placing the organisms under anaerobic conditions. Of a considerable number of compounds other than carbohydrates, calcium phosphate alone was capable of bringing about the change from pre-swarmers to rods.

The organism also appears to be affected greatly by the reaction of the soil. In the main, the normal rod rapidly changes into the pre-swarmers form in calcareous soils; acid soils cause the production of highly vacuolated cells and eventually kill the organism, while a slightly alkaline soil was found to be capable of supporting vigorous growth without altering the form of the cells.

The effect of various temperatures on the rapidity of pre-swarmers formation has been studied. Relatively high temperatures (30° and 37°) either prevent or postpone the entrance of down-grade changes.

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### KEY TO PLATES.

#### PLATE I.

- Fig. 1. Old nodule of the Broad Bean, showing ghost forms and free chromatin masses.  
Fig. 2. Red Clover organism in pre-swarmer stage.  
Fig. 3. Red Clover organism. Pre-swarmer transferred to fresh medium. Type of rod after 24 hrs.  
Fig. 4. After 72 hrs. on fresh medium.  
Fig. 5. " 96 " "  
Fig. 6. " 72 " " Showing all stages from Figs. 2 to 5.

#### PLATE II.

- Fig. 1. Red Clover organism after seven days in atmosphere of oxygen; the position of the chromatin bands indicating rapid cell division.  
Fig. 2. Red Clover organism after five days in atmosphere of nitrogen showing increased vacuolation of rods.  
Fig. 3. Red Clover organism after seven days in atmosphere of nitrogen showing still higher vacuolation.  
Fig. 4. Red Clover organism after nine days in atmosphere of nitrogen. The pre-swarmer have left the rods and are free in the medium.  
Fig. 5. Red Clover organism after nine days in atmosphere of nitrogen. A typical culture showing highly vacuolated rods with segregated chromatin. The pre-swarmer can be seen within the rods; also free in the medium.

#### PLATE III.

- Figs. 1 and 2. Lupin organism after seven days in soil water showing pre-swarmer production.  
Fig. 3. Lupin organism after seven days in atmosphere of nitrogen.  
Figs. 4 and 6. Lupin organism after nine days in soil water.  
Fig. 5. Lupin organism involution form showing segregation of the chromatin and pre-swarmer production.

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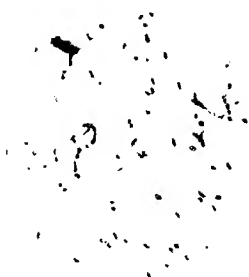




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# THE MECHANISM OF THE DECOMPOSITION OF CYANAMIDE IN THE SOIL.

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(With Five text-figures.)

A PREVIOUS investigation by the writer(1) showed that cyanamide readily breaks down, yielding ammonia in normal clay and sandy soils. The evidence, however, threw no light upon the cause or nature of this change. This question was accordingly reserved for a later investigation. The consensus of the available evidence indicated that the production of ammonia from cyanamide in the soil is due to direct bacterial action. This view was held by Immendorff(2) and Kappen(3), who concluded that in poor soils of low bacterial activities cyanamide is not converted into ammonia but is chemically transformed into dicyanodiamide. Löhnis(4) at first accounted in a similar way for the formation of ammonia from cyanamide in the soil. He(5) assumed later, however, that cyanamide is normally decomposed by soil colloids into urea or possibly some other substances, and the latter are then converted into ammonia by the soil organisms. He adduced no direct evidence of the production of urea from cyanamide in the soil.

Ulpiani(6) regarded the formation of ammonia as primarily due to a purely chemical, not a bacterial, change. He had formerly considered that cyanamide changed into dicyanodiamide in the soil and its value as a fertiliser depended on this change, an opinion also held by Perotti(7).

Ulpiani's later work, however, led him to the view that cyanamide breaks down by a purely chemical change to urea which then is converted into ammonia. The formation of urea was attributed to the soil colloids. This work was done in culture solutions of various concentrations and at various temperatures.

Our experiments were made in soil under natural conditions, using amounts of cyanamide comparable with those used in practise. Our results agree with those of Ulpiani.

Our experiments have consistently failed to show any appreciable amount of ammonia resulting from the decomposition of cyanamide in sterile soils (heated to 120° C. or 135° C.). The addition of the urease of soya-bean, however, produced considerable amounts of ammonia in these soils. This pointed to the presence of urea, which was later confirmed by the extraction of the soils by alcohol and identification of urea in the extract by the urea-nitrate test. Further experiments moreover demonstrated that urea actually remains stable in soils heated to 120° C. The addition of cyanamide to sterile soils thus leads to an accumulation of urea, which persists as such in consequence of the suppression of the necessary urea decomposing organisms.

In a similar way the addition of cyanamide to soils heated to 100° C. does not lead to an immediate production of ammonia. It forthwith yields urea, however, which then decomposes into ammonia after the recovery of the appropriate organisms.

The evidence shows, on the other hand, a rapid and progressive production of ammonia arising from the decomposition of cyanamide in unheated normal clay and sandy soils. Careful examination of these soils, however, revealed in the initial periods the presence of appreciable amounts of urea. This indicates that urea produced by the decomposition of cyanamide also accumulated to some extent under normal conditions.

The cumulative evidence thus leads to the conclusion that cyanamide in the soil is normally converted by a purely chemical process into urea and this change is not dependent on the activity of micro-organisms. The urea is then broken down to ammonia by a change which, as the curves indicate, is produced by soil organisms. Cyanamide appears to behave in this way in both clay and sandy soils, but the decomposition seems to be more rapid in the former than in the latter. The experiments have conclusively shown that cyanamide does not decompose into urea in ordinary impure quartz sand; whatever the decomposing agent may be it is not present in pure sand.

Cyanamide does not appear to break down in the manner above indicated in peat and fen soils; in these it gives rise to a relatively small production of urea under normal conditions.

The investigation has not revealed the exact nature of the decomposing agent in the soil. It is interesting to note, however, that a sample of Thanet sand taken from a boring through the London Clay near Chelmsford was found even after ignition to be active in decomposing cyanamide into urea. This particular sand(s) has been shown to contain a constituent resembling a zeolite in being reactive and possessing the

property of softening hard water by the substitution of sodium salts and possibly potassium for those of calcium and magnesium. In following up this clue it was found that the addition of a definite zeolite prehnite to ordinary inert sand produces a mixture capable of converting cyanamide into urea.

#### EXPERIMENTAL.

The cyanamide was used in the form of fresh nitrolim in which the calcium cyanamide had undergone practically no change. The bulk of the soil to be used was first thoroughly mixed together and its moisture content raised, where necessary, to 12 to 15 per cent. according to its water capacity. The soil was next passed through a 3 mm. sieve, weighed out into lots of 200 grams which were then transferred to wide-mouthed bottles of 10 oz. capacity, a fresh bottle being taken for each determination at the end of the various periods. The application of the cyanamide to the soils was made in the following manner.

In the case of unheated soils the weighed quantity of cyanamide was sprinkled on to the 200 grams of soil previously spread out on a sheet of paper; the whole was then mixed and replaced in the bottles, which were plugged with cotton-wool.

In the case of the heated soils this procedure might have led to reinfection, and therefore the bottles containing soil, etc. were first plugged with cotton-wool and then heated for the proper period at the requisite temperature. After cooling, the cyanamide was carefully and rapidly introduced into the bottles from small glass tubes, in which the cyanamide itself had been heated for the same time at the same temperature in the air-oven. Tests showed that heating under these conditions produced no chemical change in the cyanamide. After careful replugging to avoid reinfection the bottles were vigorously shaken for some considerable time to ensure an adequate mixing of the cyanamide with the soils.

In no case did heating cause a loss of more than 2 per cent. moisture in the soils. All bottles were then kept in a dark cellar at the ordinary laboratory temperature.

In order to inhibit the nitrification of ammonia produced from cyanamide, a small amount of dicyanodiamide, equivalent to thirty parts N per million dry soil, was added with the cyanamide. A previous investigation showed conclusively that dicyanodiamide does not give rise to ammonia or affect appreciably the production of ammonia from cyanamide.



THE STAGES IN THE PRODUCTION OF AMMONIA FROM  
CYANAMIDE IN SOILS.

Experiments were made to determine the relative rates of ammonia production from cyanamide in untreated soils and the same soils after heating for one half hour in the autoclave at 120° C. Both the heavy Rothamsted and the light Woburn soils were used. The results (plotted in Fig. 1 and given in Table I) show a rapid and progressive production of ammonia from cyanamide in the unsterilised soils, but they afford little evidence of ammonia resulting from the decomposition of cyanamide in the sterilised soils.

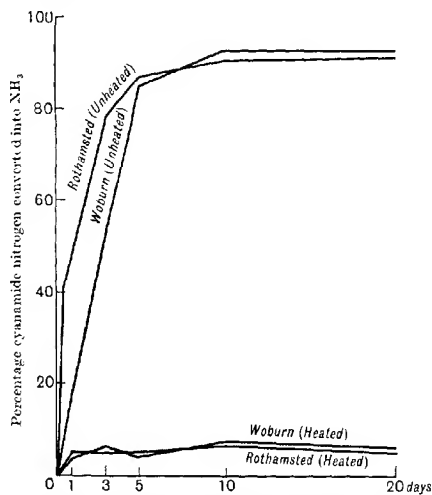


Fig. 1. Showing relative rates of ammonia production from cyanamide in unheated soils and soils heated to 120° C.

Although the sterilised soils showed little trace of ammonia production from cyanamide, there was the possibility that the decomposition had stopped at some intermediate stage. On chemical grounds the most probable stage seemed to be the formation of urea. Examination for this substance was therefore made in soil which had been stored for 20 days or more, the urease of the soya-bean being used as the testing

agent. Takeuchi(9) and also Armstrong and Horton(10) have shown this enzyme is quite specific in its action, decomposing urea only, and nothing else so far as is known. The soils were accordingly treated with

Table I.  
*Ammonia produced from Cyanamide in Soils.*

Treatment	N present as $\text{NH}_3$ per million dry soil									
	Rothamsted					Woburn				
	Control at start 4.0					Control at start 2.6				
	After 1 day	After 3 days	After 5 days	After 10 days	After 20 days	After 1 day	After 3 days	After 5 days	After 10 days	After 20 days
Control	4.0	3.4	4.0	6.7	6.7	2.6	1.9	2.6	5.2	5.2
+Cyanamide	44.5	82.3	90.3	97.1	97.1	22.0	55.5	87.8	98.2	100
Heated soil (120° C.)	9.3	19.9	23.9	25.2	25.2	7.7	7.7	19.1	17.9	21.7
+Cyanamide	14.6	14.6	29.2	31.9	30.3	12.8	14.0	23.0	25.5	26.8

Cyanamide N added = 100 parts per million dry soil.

well-powdered soya-bean and incubated at 35–40° C., the optimum temperature for the enzyme. The ammonia was then determined in the usual way. The results were as follows:

Table II.  
*Ammonia produced from Cyanamide in Sterilised Soils after addition of Soya-bean.*

Treatment	N present as $\text{NH}_3$ per million dry soil	
	Rothamsted	Woburn
Heated soil	...	23.6
+ soya-bean	...	26.2
+ cyanamide + soya-bean*	...	104.3
Heated soil + cyanamide (no soya-bean)	...	27.0

Cyanamide N added = 100 parts per million dry soil.

\* The mixture of heated soil and cyanamide had previously been stored for 20 days.

The addition of soya-bean thus resulted in a considerable production of ammonia in the sterilised soils treated with cyanamide. Further tests showed that the soya-bean does not produce any appreciable amount of ammonia direct from cyanamide.

The evidence thus indicated that the origin of the ammonia produced by soya-bean in the sterile soils was an accumulation of urea derived from cyanamide.

Table III.

*Non-formation of Ammonia by Action of Soya-bean on Cyanamide.*

Treatment					N present as $\text{NH}_3$ per million dry soil
					Rothamsted
Sterilised soil + soya-bean	...	...	...	...	26.2
ditto	ditto	+ cyanamide (freshly added)	...	...	34.7

Cyanamide N added = 100 parts per million dry soil.

Tests were subsequently made to ascertain whether urea does actually remain stable in similarly heated soils. Another set of soils was therefore made up containing urea in place of cyanamide; the quantity of added nitrogen, however, being the same. In these soils urea and ammonia were both determined after an interval of 20 days; only a small decomposition of urea into ammonia took place under these conditions.

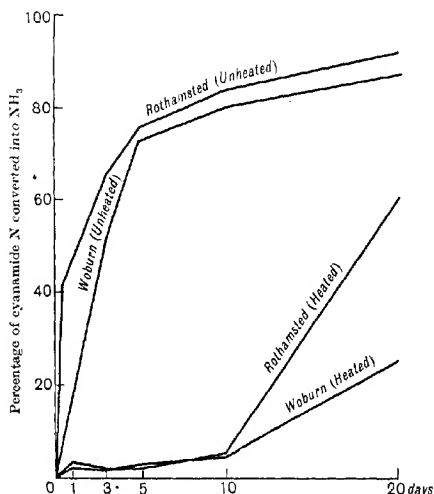


Fig. 2. Showing relative rates of ammonia production from cyanamide in unheated soils and soils heated to 100° C.

In order to confirm the production of urea from cyanamide in the sterilised soils, the latter were extracted with 96 per cent. alcohol and the solution evaporated to dryness *in vacuo*. The crystals thus obtained

were shown to include urea by means of the urea nitrate test. The application of the same test to a similar extract from the control soils gave negative results.

Table IV.

*Stability of Urea in Sterilised Soils.*

N present as  $\text{NH}_3$  per million dry soil after 20 days.

Heated soil	...	...	...	...	...	...	14.2
ditto + urea	...	...	...	...	...	...	20.7
ditto + soya-bean	...	...	...	...	...	...	22.0
ditto ditto + urea	...	...	...	...	...	...	115.0

Urea N added = 100 parts per million dry soil.

The above evidence indicates that cyanamide in the soil decomposes into urea which is then converted into ammonia by the soil organisms. The suppression of the organisms in sterilised soils, therefore, leads to a persisting accumulation of urea from cyanamide.

These conclusions were further confirmed by the behaviour of cyanamide in partially sterilised soils or those heated for half an hour at  $100^\circ\text{C}$ . In this case the production of ammonia was practically suspended for several days, after which it proceeded. The results are plotted in Fig. 2 and given in Table V.

Table V.

*Ammonia produced from Cyanamide in partially Sterilised Soils.*

N present as  $\text{NH}_3$  per million dry soil

Treatment	Rothamsted at start 5.2					Woburn at start 2.5				
	After 1 day	After 2 days	After 5 days	After 10 days	After 20 days	After 1 day	After 2 days	After 5 days	After 10 days	After 20 days
Control	5.2	5.2	5.2	3.9	3.9	2.5	2.7	2.5	2.6	2.5
+cyanamide	47.0	69.9	80.5	87.1	95.6	20.2	52.2	75.7	78.1	88.3
Heated soil ( $100^\circ\text{C}$ )	9.0	9.0	9.0	9.0	35.6	6.0	6.0	6.4	6.4	12.3
+cyanamide	11.6	10.3	10.3	14.2	95.6	8.9	7.5	8.7	11.2	37.7

Cyanamide N added = 100 parts per million dry soil.

Table VI.

*Formation of Urea from Cyanamide in partially Sterilised Soils.*

Treatment	N present as $\text{NH}_3$ per million dry soil	
	Rothamsted	Woburn
Heated soil ( $100^\circ\text{C}$ ) + cyanamide	11.6	7.8
Ditto* + soya-bean	64.9	34.2

Cyanamide N added = 100 parts per million dry soil.

\* By "ditto" is to be understood in each case the mixture used in the line above.

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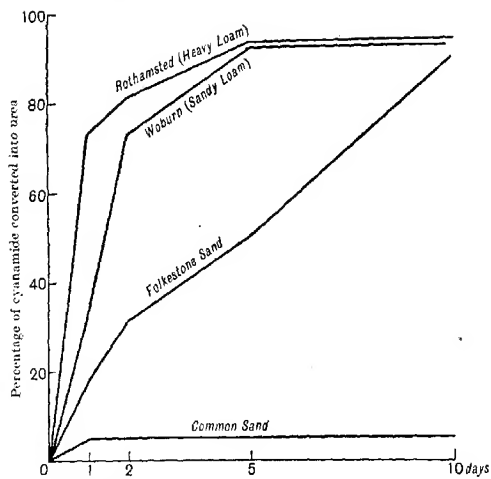
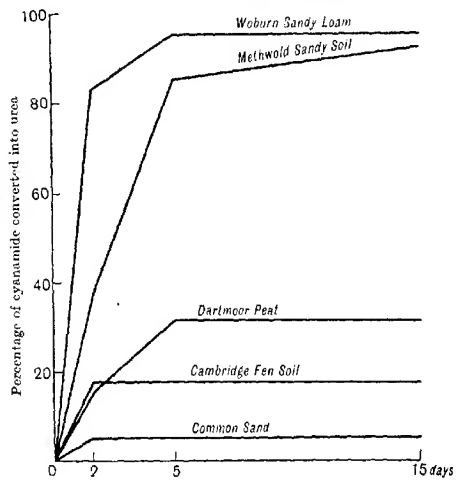


Fig. 3. Showing rates of conversion of cyanamide into urea.



In the first 10 days the addition of cyanamide resulted in but a small production of ammonia in the heated soils. Treatment of these soils with soya-bean, however, produced a considerable amount of ammonia at the end of the 4th day.

The above results thus show that cyanamide in the soil heated to 100° C. first decomposes to urea which subsequently changes into ammonia. The results further indicated that this subsequent change is biological because it is almost wholly suspended during the first 10 days, after which it becomes much more rapid.

Table VII.

*Production of Urea and Ammonia from Cyanamide in Unheated Soils.*

N present as NH <sub>3</sub> per million dry soil.													
Treatment	Rothamsted, at start 2.6					Woburn, at start 1.8					Folkestone, at start 13.6		
	After 1 day	After 2 days	After 5 days	After 10 days	After 1 day	After 2 days	After 5 days	After 10 days	After 1 day	After 2 days	After 5 days	After 10 days	After 10 days
Control + soya-bean	19.7	19.7	19.7	19.0	15.2	15.7	15.2	15.2	26.0	26.0	26.5	32.2	
Ditto + cyanamide	93.2	100.4	113.0	112.8	46.9	89.0	108.0	108.0	43.4	57.0	74.4	122.6	
Difference = rates of urea production	73.5	80.7	93.3	93.8	31.7	73.3	92.8	92.8	17.4	31.0	47.9	90.4	
Control	3.9	3.9	3.0	2.6	1.8	1.8	2.0	1.8	13.6	13.6	13.6	18.6	
+ cyanamide	57.8	76.2	97.2	97.2	29.2	58.4	83.8	90.2	14.8	17.3	52.1	106.6	
Difference = rates of ammonia production	53.9	72.3	94.2	94.6	27.4	56.6	81.8	88.4	1.2	3.7	38.5	88.0	

Treatment	Woburn Sandy loam Control at start 1.9			Methwold Sandy soil Control at start 12.4			Leighton Buzzard Ordinary sand Control at start 1.3		
	After 2 days	After 5 days	After 15 days	After 2 days	After 5 days	After 15 days	After 2 days	After 5 days	After 15 days
Control + soya-bean	12.7	12.7	15.2	26.0	26.0	26.0	14.1	14.1	14.5
Ditto + cyanamide	95.3	107.9	108.0	63.2	110.3	117.8	19.2	19.2	19.7
Control ...	...	1.9	1.7	1.8	12.4	12.4	1.3	1.3	1.3
+ cyanamide	...	57.5	83.8	90.2	50.7	95.4	107.9	5.0	5.1

Cyanamide N added = 100 parts per million dry matter.

The final step was to ascertain whether the change proceeded in the same manner in ordinary unheated soils. The figures in Table VII show that this is the case. The soils used were from Rothamsted (Clay-with-flints), Woburn (Lower greensand), a poor heath sand uncultivated, from Blackheath, Surrey (Folkestone beds of the Lower greensand

formation), the very light sandy soil from Methwold, Norfolk; and sand from a sand pit at Leighton Buzzard, Beds (Lower greensand). The results are given in Table VII and plotted in Figs. 3 and 4.

The cumulative evidence thus leads to the conclusion that cyanamide in these soils is decomposed by a purely chemical process into urea, and the latter is subsequently converted into ammonia by the soil organisms. There is at first an accumulation of urea even in the unheated soils and a very marked accumulation in the heated soils. Cyanamide appears to undergo the same change in both clay and sandy soils, even in a soil containing no more than 0.9 per cent. clay, as in the Folkestone sand soils. In the sand from the sand pit, however, there is no formation of either urea or ammonia from cyanamide. The decomposition is the more rapid in the soils containing the larger proportion of clay. The greater persistence of the urea in the poor uncultivated Folkestone sand, as compared with the cultivated Rothamsted and Woburn soils, is both interesting and significant.

#### SOILS IN WHICH THE FORMATION OF UREA FROM CYANAMIDE DOES NOT TAKE PLACE.

In Table VII it is shown that the formation of urea from cyanamide does not take place in sand from a sand pit. Table VIII shows that the action likewise does not occur in peat and fen soils.

Table VIII.

#### *Non-formation of Urea from Cyanamide in Peat and Fen Soils.*

N present as  $\text{NH}_3$  per million dry soil.

Treatment	Dartmoor Peat Control at start 15.6			Cambridge Fen Control at start 4.7		
	After 2 days	After 5 days	After 15 days	After 2 days	After 5 days	After 15 days
Control + soya-bean	21.8	21.8	40.9	9.5	9.5	9.0
Ditto + cyanamide	57.5	53.2	72.0	27.1	27.0	27.5

Cyanamide N added = 100 parts per million dry soil.

#### THE MECHANISM OF THE PRODUCTION OF UREA FROM CYANAMIDE IN SOIL.

Further investigation showed that the decomposition of cyanamide into urea still proceeded in a soil previously heated as high as  $135^\circ\text{C}$ . for half an hour in the autoclave. It is evident therefore that the action is not brought about by living organisms or by an enzyme decomposable—as most enzymes are—at  $135^\circ\text{C}$ .

Table IX.

*Production of Urea from Cyanamide in soil heated to 135° C.*N present as  $\text{NH}_3$  per million dry soil. After 10 days.

Heated soil (135° C.)	...	...	...	13.8
+ soya-bean	...	...	...	27.0
Ditto + cyanamide	...	...	...	101.3
Heated soil + cyanamide	...	...	...	18.8

Cyanamide N added = 100 parts per million dry soil.

The change was found to occur in a sample of Thanet sand taken from a boring through the London Clay at Broomfield in Essex.

Table X.

• *Production of Urea from Cyanamide in Thanet Sand.*

## (a) Unignited material.

N present as  $\text{NH}_3$  per million dry sand. Control at start 19.8.

Treatment	After 1 day	After 2 days	After 5 days
Control + soya-bean	31.0	30.1	31.0
Ditto + cyanamide	97.9	100.6	133.8
Control ... ..	19.5	19.8	19.9
+ cyanamide ...	19.8	19.8	37.2

Cyanamide N added = 100 parts per million dry sand.

## (b) Ignited Thanet Sand.

N present as  $\text{NH}_3$  per million dry sand.

Treatment	After 1 day	After 3 days
Ignited Thanet sand + soya-bean ...	45.8	45.0
Ditto + cyanamide ... ..	84.5	108.1

Cyanamide N added = 100 parts per million dry sand.

The Thanet sand was then ignited at a dull red heat but it still remained active in decomposing cyanamide into urea (Table X and Fig. 5). It appears therefore that the decomposing agent, in this case at any rate, is inorganic in its nature. This Thanet sand possessed the property of softening hard water by the substitution of sodium and possibly potassium salts for calcium. Presumably therefore it contained a constituent resembling a zeolite in being reactive. A definite zeolite, viz. prehnite, was therefore tested and when added to inert quartz sand it gave a mixture capable of converting cyanamide into urea. Table XI



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shows the extent to which action had proceeded after 5 days. Further investigation promises very interesting results; this is being carried out in the Rothamsted laboratories by Mr A. G. Pollard.

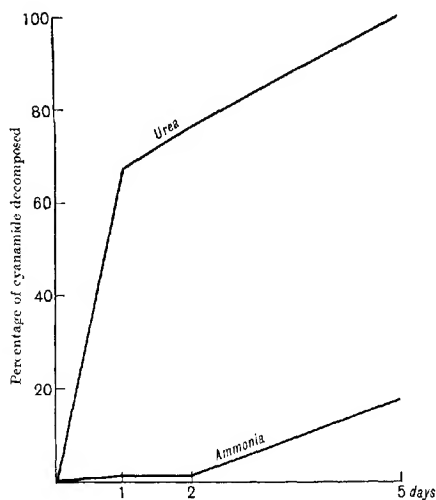


Fig. 5. Showing relative rates of urea and ammonia formation from cyanamide in Thanet sand.

Table XI.

*Production of Urea from Cyanamide in a Mixture of Inert Sand and a Zeolite (Prehnite).*

Treatment	N present as $\text{NH}_3$ per million dry matter	
	After 5 days	
Inert sand + prehnite    ...    ...    ...    ...	1.2	
Inert sand + prehnite + soya-bean    ...    ...    ...	11.1	
Inert sand + prehnite + cyanamide + soya-bean    ...    ...    ...	39.6	
Inert sand + prehnite + cyanamide    ...    ...    ...	4.9	

Finely ground prehnite added = 9 per cent. of mixture.

Cyanamide nitrogen added = 100 parts per million dry matter.

## THE DETERMINATION OF AMMONIA IN THE SOIL.

The ammonia in the soil was determined by the aeration method used in the previous investigation and shown to produce no appreciable formation of ammonia by hydrolysis from cyanamide. A stronger current of air, however, was used whereby it was found possible to recover, with satisfactorily concordant duplicates, approximately 95 per cent. of any added ammonia in the soil. Average results of repeated tests were:

N added = 100 parts per million dry soil.				
N recovered per million dry soil				
			Rothamsted	Woburn
Soil alone	...	...	3.2	1.3
Soil and ammonium sulphate	...	...	98.1	99.1

## THE DETERMINATION OF UREA IN THE SOIL.

The amounts of urea in the soil were determined by the use of the urease of the soya-bean. Prior to estimating the ammonia by the aeration method the soil was treated with well-powdered soya-bean, using 1 gram of the latter to 25 grams of the fresh soil. After thorough mixing the whole was incubated at 35° C.-40° C. for one hour, and then aerated after cooling for the determination of the ammonia. Repeated tests showed that approximately 90 per cent. of the urea added to a sterile soil or sand could be recovered as ammonia. Aeration caused no appreciable decomposition of the urea. As a small amount of ammonia was evolved by the soya-bean, a control experiment with soya-bean and soil was carried out in each case. Typical results were:

N recovered as NH <sub>3</sub> per million dry soil							
Treatment							
Sterile soil      Sand							
Control	...	...	...	...	...	14.2	1.3
Ditto + soya-bean	...	...	...	...	...	22.0	14.1
Ditto ditto + cyanamide (100 parts nitrogen)	...	...	...	...	...	115.5	102.0
Control + urea (100 parts nitrogen) (no soya-bean)	...	...	...	...	...	20.7	3.8

The added urea contained 100 parts of nitrogen as also did the added cyanamide.

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## A NOTE ON THE SHERAQI SOILS OF EGYPT. A STUDY IN PARTIAL STERILISATION.

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(With One text-figure.)

In a previous communication<sup>1</sup> attention was called to the possibilities of partial sterilisation under field conditions in the case of the summer fallow of Egyptian agriculture.

This fallow period or "sheraqi" is particularly characteristic of the basin system of agriculture during the interval between the harvest of the winter crop and the Nile flood, but it is also common under perennial conditions of irrigation after the winter crops.

The conditions may be stated simply as extreme dryness with relatively high temperatures. Besides checking the bacteriological activity of the soil, this causes the soil to shrink and to crack to a considerable depth and this cracking probably plays an important part in the maintenance of the tractability of the heavy soils of the Nile valley. In the writer's gardening experience the effect is very similar to that exerted by a severe frost under English conditions of farming.

According to V. M. Mosseri<sup>2</sup> this cracking is probably fundamental in the maintenance of the fertility of the soils of the Nile valley under the classical system of Egyptian farming because it prevents the accumulation of salts and allows of perfect aeration with probably further chemical and physical effects. This author has shown that salts concentrate on the outside of the lumps of soil and are hence easily washed away by the irrigation or flood water. The cracks permit the access of air to relatively great depths of the soil.

It is not intended in this paper to discuss this undoubted important physical effect of the sheraqi period, but to place on record some of the data obtained in 1918 and 1919 relating to the biological aspect of the question.

<sup>1</sup> This *Journal*, 1919, ix. 216.

<sup>2</sup> *Bulletin de l'Institut Egyptien*, 1909, "Le drainage en Egypte." A further communication on this subject by V. M. Mosseri and C. Audébeau is in preparation.

E. J. Russell and H. B. Hutchinson<sup>1</sup> suggest that drought or prolonged heating at 40° C. have very similar effects on the soil as the treatment by heating at higher temperatures or by means of volatile antiseptics.

This partial sterilisation of the soils is followed by an increased bacteriological activity and it was of special interest to obtain some positive evidence of this phenomenon in the case of these Egyptian soils.

#### FIELD CONDITIONS.

The photograph of the Zenar Basin at Assiut illustrates the characteristic effect of the sheraqi period on these soils.

At the beginning of the summer fallow the moisture content may be fairly high, up to 16 per cent., but this rapidly falls to about 5 per cent.



Zenar Basin, Assiut, August 1918.

The temperature down to 10 cm. approaches 40° C. daily. The following Table I illustrates characteristic temperature conditions for one day in June 1919.

<sup>1</sup> E. J. Russell and H. B. Hutchinson. *This Journal*, 1913, v. 152.

Table I.

*Temperature conditions of Sheraqi soil. Bahdim, June 27, 1919.*  
*Degrees Centigrade.*

			1 p.m.	3 p.m.	5 p.m.
Surface	...	...	55.0	53.5	48.5
5 cm. depth	...	...	39.0	38.9	43.0
10 cm. "	...	...	37.0	37.0	36.3
20 cm. "	...	...	—	33.3	33.3

Bacterial numbers are relatively low, about one million per gramme of dry soil, and no activity has been observed. Nitrates do not accumulate.

The conditions are thus distinctly unfavourable to biological activity and the active period on the renewal of favourable conditions, particularly in relation to the supply of water, ought to show the characteristic abnormal activity. Bacteria ought to multiply more rapidly than in soil that has not been under these conditions and there ought to be an increased accumulation of available nitrogen as ammonia or as nitrate.

It is obviously difficult to obtain strict comparative data on this point, particularly as it is difficult to secure an untreated soil, but the data given below show that this increased activity over soils that have not been sheraqi does take place.

Protozoa are not entirely killed off except possibly under the extreme conditions of the basin lands but they are certainly checked. In the hands of a competent biologist there would seem to be ample material in these Egyptian soils for an examination of E. J. Russell's hypothesis concerning the activity of protozoa in limiting the bacteriological activity of the soil.

#### EXPERIMENTAL.

The main difficulty in obtaining positive evidence was to obtain a representative sample of soil that had not been under the sheraqi conditions.

In 1919 a piece of rich bersim (clover) soil was selected immediately after the cattle had fed off the last cutting. Samples were taken from three different places and kept at about 20 per cent. moisture in lots of 1 kilo.

After one month a second sample was taken from the same field and again after two months.

Unfortunately the first sample was too rich; probably one of the places from which it was taken had been soaked by the urine of some animal. The whole sample showed an initial nitrate nitrogen content of 60 parts per million of dry soil and was therefore rejected. In spite of its richness its highest number of bacteria was never more than 17 millions per gramme of dry soil during storage at 20 per cent. moisture content for 90 days. Bacterial counts and determinations of nitrate were made at intervals on the stored samples. The temperature of storage was 28–30° C.

Table II.

*Numbers of bacteria and amounts of nitrate in sheraqi soils after moistening up to 20 per cent. water content. 1918.*

	Number of days	Bacteria, millions per gramme of dry soil	Nitrate Nitrogen, parts per million of dry soil	Nitrate produced
$S_1$ sampled July 1st	0	5.3	24.1	— <sup>a</sup>
Moisture = 7.2 %	5	34.6	38.2	14.1
	15	21.1	51.5	27.4
	30	10.1	54.4	30.3
	58	17.1	84.4	60.3
$S_2$ sampled August 1st	0	1.6	26.8	—
Moisture = 4.1 %	5	22.5	49.5	22.7
	14	—	61.2	35.4
	31	93.0	68.5	41.7

In the year 1919 a similar piece of land was selected, a small cutting of bersim being taken before sampling began. In this case the first sample, taken on May 27 before sheraqi conditions had set in, was kept in bulk under more or less dormant conditions in the laboratory.

On July 26 the same piece of land was again sampled and the two sets moistened up to 21 per cent. moisture and stored at 30° C. in lots of 1 kilo.

Determinations of nitrate, ammonia and bacteria numbers were then made periodically.

The untreated soil contained on sampling 14 per cent. of moisture which fell to 10 per cent. during storage.

During this period a little nitrate accumulated in excess of that present in the sheraqi sample when sampled two months later.

In both years the sheraqi soils after moistening up show an increased biological activity over the untreated soils, characteristic of partial

sterilisation, the number of bacteria being higher and there being a more rapid accumulation of available nitrogen entirely parallel with the cases investigated by E. J. Russell and his co-workers.

Table III.

*Numbers of bacteria and amounts of nitrate and ammonia in sheraqi soils after moistening up to 21 per cent. water content. 1919.*

	Number of days	Bacteria, millions per gramme of dry soil	Nitrogen, parts per million of dry soil		Nitrate produced
			As ammonia	As nitrate	
Untreated	0	3.4	nil	18.6	—
Sampled May 27th	5	16.4	—	31.7	13.1
Moisture = 14 %	15	15.0	—	32.6	14.0
	32	10.0	—	41.9	23.3
	62	9.1	—	51.2	32.6
	90	13.5	—	55.5	36.9
Sheraqui	0	2.1	10	8.2	—
Sampled July 26th	5	17.5	4	23.7	15.5
Moisture = 5.5 %	15	28.8	—	25.9	17.7
	32	24.1	7	40.0	31.8
	62	13.9	—	51.2	43.0
	90	18.4	—	61.3	53.1

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## NUMBERS OF PROTOZOA IN CERTAIN ROTHAMSTED SOILS<sup>1</sup>.

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(With Twenty text-figures.)

### INTRODUCTION.

ALTHOUGH during the last few years a good deal of work has been done on the soil protozoa, very little is known as yet as to their mode of life, behaviour and relations with the other soil organisms; so much is this the case that even the fact that they lead a trophic life in soil is often disputed. Since Russell and Hutchinson(16, 17) in their work on the partial sterilisation of soil first discussed the possible relations existing between the soil protozoa and bacteria, the question of the activity of protozoa in soil has become important. They found that partial sterilisation brought about an improvement in the soil as a medium for the growth of bacteria by the removal of a limiting factor, and further they showed that this limiting factor possessed many of the characteristics of a living organism. Provisionally they regarded the protozoa as constituting one of the factors limiting bacterial development in soil; the hypothesis therefore is based on the assumption that the protozoa are trophic. It has been the object of this work to ascertain whether these organisms can live and multiply in the soil under wholly normal physical and cultural conditions, and also to throw some light upon the inter-relations between this group of animals and the soil bacteria. Among recent investigators Martin and Lewin(11) and Goodey(7) are practically the only ones who state that protozoa other than flagellates are trophic in soil even when the moisture content is not above the average. Martin and Lewin claim this for amoebæ and flagellates, Goodey for amoebæ only. Martin and Lewin succeeded in making preparations of trophic amoebæ, thecamoebæ and flagellates either by adding suitable fixatives, such as picric alcohol, to the soil and floating cover slips on the surface of the liquid, or by passing a stream of air bubbles through a vertical tube containing a suspension of soil in water, and letting the bubbles break on a cover slip at the top for a short time. When either of these methods results in the appearance of trophic forms on the cover slips

<sup>1</sup> This work was carried out before Mr Cutler's method for distinguishing between the total and the active numbers of protozoa was devised. The figures quoted in this paper always refer to total (active + cystic) numbers.

it is a satisfactory proof that trophic forms were present in the original soil, but there are certain drawbacks attached to both methods, as there appear to be physical conditions<sup>1</sup> under which the protozoa cannot be washed out of the soil with such ease and the cover slips remain blank, and further there is the faint possibility that sudden excystment may be induced by the treatment that the soil undergoes. According to Martin and Lewin, amœbæ, thecamœbæ and flagellates are ordinarily trophic in the soils that they used, the amœbæ and thecamœbæ being more numerous than the flagellates. Their soils included a cucumber sick soil, a soil from a seedling bed, containing sand and leaf mould, but no manure, a woodland soil very rich in leaf mould, and three of the Rothamsted field soils taken from Broadbalk, dunged plot and unmanured plot, and from a fallow plot on Agdell. Goodey, working at Rothamsted (5), thinks that ciliates are probably not trophic. Waksman working in U.S.A. (20) states that "flagellates are the most common soil protozoa found active in the soil with moisture content too low for the development of the other groups," but he makes no mention of the amœbæ, and Sherman, also working in U.S.A. (18), agrees that flagellates are in most soils the only active forms. With the heavy Rothamsted soils Martin and Lewin's methods often give negative results, but when they succeed the fauna comprises many more amœbæ than flagellates, moreover the amœbæ both from their size and from their known habit of feeding on bacteria are more likely to make an impression upon the bacterial numbers than are the very much smaller flagellates which are in some cases not even holozoic. For these reasons in the present instance the amœbæ alone are considered, except in a few cases where it has seemed useful to quote the numbers for ciliates or flagellates. It is interesting to notice in this connexion that Cauda and Sangiorgi, working at Turin (1), invariably obtain from their soils comparatively high numbers of amœbæ, and in two cases amœbæ only, the flagellates and ciliates both being absent. The thecamœbæ, which are often present in numbers up to 1000 or even more per gramme, are also neglected as they arise very late in the cultures, generally not until at least three weeks have elapsed, and to deal with them adequately requires an increase of apparatus which has hitherto been impracticable. Records of their appearance have been kept in some cases. For instance on May 3rd, 1916, 10 petri dishes containing nutrient agar were inoculated with 0.5 gramme of soil from Broadbalk, Plot 2, and enough sterile water was added to each plate

<sup>1</sup> Doubtless connected with surface energy (Cutler, *Journ. of Agric. Sci.* ix. part iv. 1919).

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to moisten the surface. Thecamæbæ appeared on the plates marked with a × as follows:

Table I.

*Thecamæbæ in soil of Broadbalk, Plot 2, May 1916.*

	Plates									
	1	2	3	4	5	6	7	8	9	10
May 31	...	×	...	...	...	...	...	...	×	×
June 5	×	×	...	...	...	...	...	...	×	...
June 10	...	...	...	×	...	...	...	...	×	...
June 15	×	×	×	×	...	...	×	...	×	×
June 19	×	×	...	...	...	...	...	...	×	...
June 22	×	×	×	×	×	...	×	×	×	...
June 29	...	...	×	×	×	...	...	×	×	×
July 3	×	×	×	×	×	×	×	×	×	×

On September 7th, 1916, petri dishes were inoculated with 1 c.c. from some of the dilution bottles used for counting the protozoa in Broadbalk, Plot 2.

Table II.

*Thecamæbæ in soil of Broadbalk, Plot 2, Sept. 1916.*

	Dilutions			
	1/10	1/100	1/1000	1/2500
September 13	0	0	0	0
September 20	0	0	0	0
October 3	×	0	0	0
October 5	×	×	×	0
October 10	×	×	×	0

Strong evidence for the existence of flagellates and amœbæ in the trophic state is derived from observations on the fluctuations in their numbers, these fluctuations being of a very definite character and in no way due to chance.

## EXPERIMENTAL.

The method used for counting the protozoa is an adaptation of the dilution method often employed in estimating bacterial numbers, and although such a means of counting can never give the absolute number of organisms present, yet it furnishes results which have a definite relative value. Each sample of soil used is composed of several six inch borings taken with a soil auger and passed through a 3 mm. sieve; 10 grammes are weighed out and shaken for four minutes in sterile tap water and this forms the initial dilution of 1/10 from which all the others are prepared. Four 1 c.c. samples are taken from each dilution bottle to give four parallel series of cultures.

The apparatus must be sterile and the suspensions thoroughly shaken so that the liquid is as homogeneous as possible when the samples for incubation are taken with the pipette. The medium used is a nutrient agar, containing 0.3 per cent. lemco, sloped in small test-tubes<sup>1</sup> so that there is a certain amount of agar slope above the 1 c.c. of liquid from the dilution bottle. The cultures are incubated for a minimum period of five days before examination, at a temperature of about 18° C. Samples have been taken at fairly regular intervals of seven days from Broadbalk, Plot 2, which carries wheat every year and receives 14 tons of farmyard manure per acre every autumn, and from Great Harpenden Field, which in 1915, 1916, 1917 was cropped with cereals and in 1918 with clover and had received no dung since 1914; samples have also been taken on a few occasions from Broadbalk, Plot 3, which has received no manure since 1839, and from Barnfield, Plot 10, cropped with mangolds and receiving 14 tons farmyard manure per acre every year. The numbers of protozoa fluctuate even from day to day in the top six inches of the field soils under observation; flagellates are nearly always present in numbers varying from 1000 to 100,000 per gramme, amœbæ too are generally to be found, though their numbers are lower, ranging between 100 and 50,000 per gramme and very occasionally rising to 100,000; the ciliates only appear from time to time and seldom exceed 1000 per gramme. This method of counting of course allows of no differentiation between the organisms that are present in the soil in the trophic state and those that are there as cysts; it is possible however to make such a distinction by using a device of Cunningham's(2) which depends upon heating the dilutions to 58° C. to kill off all trophic forms before inoculating the culture tubes.

Miss L. M. Underwood, B.Sc. gave valuable assistance in the routine work during the period December 1916—April 1917.

Curves 1 to 13<sup>2</sup> show the numbers of amœbæ in Broadbalk, Plot 2, and in Great Harpenden Field, the samples being taken at intervals of about seven days over a period extending from May 1916 to August 1919. These numbers change considerably and at first sight it may appear that the fluctuations are entirely due to chance, that at one point the soil may be rich in amœbæ while in another it is barren, implying that the amœbæ are not native to the soil but are deposited there quite fortuitously, either from the air, just as protozoa appear in a hay infusion which is left uncovered, or when manure is applied. That chance is not

<sup>1</sup> Mr Cutler in these laboratories uses petri dishes (see p. 133).

<sup>2</sup> I am indebted to Mr D. W. Cutler for Fig. 13.

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alone responsible for the varying numbers and that the amœbæ are really indigenous to the soil is quite clear after a consideration of the following facts:

1. Samples of soil taken at the same time from different borings in the same field when dealt with separately yield almost identical results (Table III). In actual practice however each sample that is used consists of 6-10 such borings intimately mixed together, so that even the small differences which exist between the separate parts sink into insignificance.

Table III.

*Numbers of protozoa per gramme in samples of soil taken from different parts of the same plot.*

### Great Harpenden Field.

Date	Sample No.	Amœbæ	Flagellates	Ciliates
Dec. 3, 1915	1	below 100	10,000	below 100
	2	" 100	10,000	" 100
	3	" 100	10,000	" 100
	4	" 100	10,000	" 100
Dec. 10, 1915	1	" 100	10,000	" 100
	2	" 100	7,500	" 100
	3	" 100	10,000	" 100
	4	" 100	10,000	" 100

### Broadbalk, Plot 2.

Feb. 16, 1916	1	2500	50,000	100
	2	2500	50,000	100
	3	2500	75,000	100
	4	2500	50,000	below 100
	5	2500	75,000	100

2. The curves for the two fields in general show close similarity; this is well shown in Figs. 5 and 6, and 9 and 10, in fact out of the 27 points in Figs. 5 and 6, 24 correspond, while in Figs. 9 and 10 where 12 counts are shown, eight correspond. If chance is to explain such parallelism it is necessary to imagine that the samples taken from the two different fields on the same day both happen to be rich in cysts or both happen to be poor in them.

3. The addition of dung to the field is not followed by an immediate and sustained rise in the numbers of protozoa as it would be were the dung the chief source of the soil fauna; for instance in Fig. 9 where farm-yard manure was added on October 24th and 25th, at the rate of 14 tons per acre, there is a rise in the amœba curve on the 31st which is followed by a substantial fall, and further, this rise and the subsequent one at the

end of November are paralleled in Harpenden Field (see Fig. 10) which received no manure at this date. The bacteria do apparently increase in numbers and remain fairly high from October 24th to November 10th when they too fall.

These three considerations lead to the conclusion that not only is there a protozoan fauna in certain field soils, but that this fauna is in the trophic condition and able to multiply with rapidity under certain conditions; thus in five days the number of amœbæ may rise from 5000 to 50,000 per gramme, as in Fig. 9 between October 29th and November 3rd. It may be suggested that in spite of this the amœbæ may still only be present in cysts but that their cysts are reproductive, and that where 5000 cysts each containing one amœba occurred in 1 gramme of soil in October 29th by November 3rd there were still 5000 cysts but each contained 10 amœbæ. Unfortunately our knowledge of the life-histories of these animals is insufficient to rule this suggestion out of court at once, but the investigations which have been carried out by numerous observers on free-living "limax" amœbæ hitherto have certainly not led to the discovery of such a stage of reproduction in the cyst. Further, where no amœbæ are recorded it means that although a few may have been present their numbers certainly fell well below 100 per gramme, and it is very difficult to imagine that so few cysts could give rise to 5000 amœbæ in four days, as occurs in Fig. 5 between March 8th and 12th, without excystment and a trophic period however short.

Certain experiments carried out in the winter of 1915-16 give the following results concerning the vertical distribution of protozoa in the soil:

Table IV.

*Numbers of protozoa per gramme at different depths in the soil.*

Date	Depth in inches			
	6	12	18	
Feb. 2, 1916	2500	0	0	Amœbæ
	10,000	100	100	Flagellates
	100	0	0	Ciliates
Feb. 3, 1916	1000	0	0	Amœbæ
	7500	1000	100	Flagellates
	100	0	0	Ciliates

This shows that the protozoa are practically confined to the top six inches in these field soils, and later work indicates that probably they occur very sparsely below the top four inches. Waksman<sup>(20)</sup> also finds that below

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12 inches the soil is practically free from protozoa while far the greatest number is found just below the surface.

It is very difficult to give any information as to the genera and species of protozoa that can be found in soil; for practical purposes it has been convenient to divide them up into four great groups: amœbæ, thecamœbæ, flagellates, and ciliates, but this is obviously a most unsatisfactory classification. The investigation of the soil protozoa is still in its early stages and undoubtedly many new forms will be described. Unfortunately the identification of the amœbæ and flagellates presents a good deal of difficulty since it is necessary to follow out the life-history before a species can be named with any degree of certainty, and there is a striking lack of satisfactory description in the literature dealing with them. In several cases new specific names have been assigned but the data given are quite insufficient to ensure the recognition of the species by other observers.

The position as regards the occurrence of active protozoa in the soils under consideration may be summed up as follows: in arable soil, whether entirely unmanured or rich in farmyard manure, there is an extensive protozoan fauna, at least in the top six inches, which flourishes and multiplies, obtaining a great part of its food from the bacteria that are invariably present. This fauna is in great part indigenous to the soil though some of its members probably arrive there by chance. For instance it seems likely that *Chlamydomorphys* sp. is introduced in dung since it is found in the dunged, but not as yet in the undunged, plot on Broadbalk: it also occurs in cultures of farmyard manure and is known to be an inhabitant of the intestine in some animals. In the types of soil examined the richer the soil in organic matter the richer it is found to be in protozoa, especially in amœbæ and thecamœbæ. Thus Broadbalk, dunged plot, gives consistently higher numbers than Great Harpenden Field (Table V) and on one or two occasions when counts have been made on glasshouse soils the numbers have been high compared with those of the two field soils.

A cursory glance at curves 1-13 shows that there is certainly some kind of interaction between amœbæ and bacteria, for where the bacteria are relatively high the amœbæ are as a rule relatively low, and *vice versa*. Given that the numbers quoted have a real meaning and that, although they do not represent the numbers of micro-organisms actually in the soil, they show the rise and fall in the numbers of those organisms, the cause of these fluctuations must next be considered. The most obvious suggestion to put forward is that the changes in both curves

are due to the changes in the physical factors that make up the environment. In the present instance only three of these factors have been dealt with, namely the soil moisture, the temperature and the rainfall. As a working hypothesis it may be presumed that a high percentage of moisture in the soil, short of water-logging, may be beneficial to micro-organic life, and that a high temperature may also promote growth and reproduction.

Table V.

*Comparison of numbers per gramme of protozoa in Broadbalk, dunged plot, and Great Harpenden Field. The figures in each case are the average of ten counts.*

Date	Broadbalk dunged plot (containing 10.0 per cent. organic matter)			Great Harpenden Field (containing 5.7 per cent. organic matter)		
	F	C	A	F	C	A
Feb. 1—March 5, 1917	32,000	20	1500	13,500	10	500
March 8—April 15, 1917	29,800	40	1400	9300	0	500
April 17—June 6, 1917	23,300	130	1600	7100	20	500
June 13—Sept. 20, 1917	31,200	120	18,600	25,700	10	17,000
Oct. 10—Dec. 15, 1917	42,300	20	23,200	23,300	10	10,000
Dec. 21—March 6, 1918	20,500	40	2200	12,000	0	1500
March 13—June 5, 1918	19,700	20	5100	13,500	0	450

*Rainfall.* There is no definite correlation between the curves representing the rainfall and those for the bacteria and protozoa. Occasionally a heavy fall of rain is followed by high numbers but by no means often enough to justify the conclusion from these data that the numbers of either protozoa or bacteria depend upon the rainfall. On January 16th, 1918, there is a rise in the bacteria in both fields (Figs. 11 and 12), and there is also a very heavy rainfall on the 15th (Fig. 19), as the percentage of moisture for the count is low in Broadbalk and in no way exceptional in Harpenden Field, and as the temperature is only 35.5° F. it is possible that in this case the rainfall must be called in to explain the bacterial numbers. At the same time this is the only case where any change in the biological curves might be explained by reference to the rainfall, so that the chances are strongly in favour of its being a coincidence.

*Moisture Content.* There is a very fair degree of correspondence between the curves for moisture content and the bacteria, and as might be expected the agreement is more marked when the temperature is fairly high, from May to October, than it is during the winter months. As a general rule the amœbæ are low when the moisture content is high, while the percentage of moisture is never low enough in these soils



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to act as a limiting factor to the protozoa. This conclusion is contrary to that arrived at by certain of the American soil protozoologists, e.g. Koch<sup>(9)</sup> and Sherman<sup>(10)</sup>, who have found that their protozoa are often trophic only in soils with an exceptionally high moisture content.

*Temperature.* Temperature seems to bear no special relation to the biological curves, a fact which is not surprising on considering how very little protozoa in cultures appear to be influenced by changes in temperature.

It will be noticed that the amœbæ are apparently unaffected by any of the three physical factors under consideration. In an environment as complex as is the soil it is impossible to analyse thoroughly the action and reaction between any two of the factors that build it up. Moreover there are many other factors, both physical and biological, which have not been touched upon yet and which may well have a profound effect upon the micro-organisms. One may conclude however that a warm, moist condition of the soil is favourable on the whole to the growth of bacteria, but does not encourage the amœbæ.

In this work only two soils have been dealt with in any detail, Broadbalk, Plot 2, which affords an example of a well-manured arable soil, and Great Harpenden Field which receives a comparatively small quantity of manure; the fauna of pasture land has not been considered at all nor has that from other soils.

### CONCLUSIONS.

1. Flagellates, amœbæ and thecamœbæ are usually present in these soils in the trophic condition and in comparatively large numbers, so that there is an extensive population actively in search of food.
2. The protozoan fauna is practically confined to the top six inches of the soil.
3. There is a definite inverse relation between the numbers of bacteria and amœbæ.
4. The amœbæ are uninfluenced by variations in the water content and temperature of the soil and by the rainfall.
5. The richer the soil is in organic matter the richer it is in protozoa, especially amœbæ and thecamœbæ.

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Curves 1—13 show the moisture content and numbers of bacteria and amœbæ (active + cystic) in the top six inches of soil from Broadbalk, Plot 2, and Great Harpenden Field at various dates from May 10, 1916 to July 9, 1919.

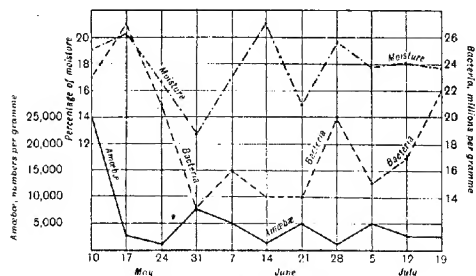


Fig. 1. Broadbalk, Plot 2, May 10—July 19, 1916.

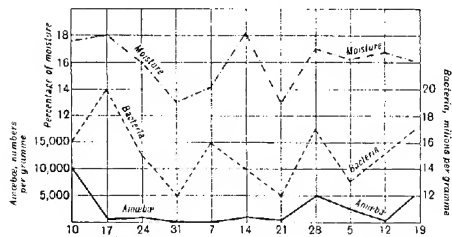


Fig. 2. Great Harpenden Field, May 10—July 19, 1916.

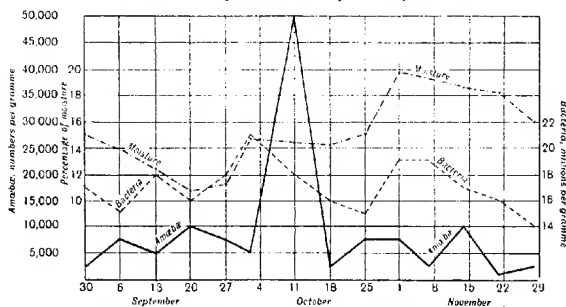


Fig. 3. Broadbalk, Plot 2 August 30—November 29, 1916.

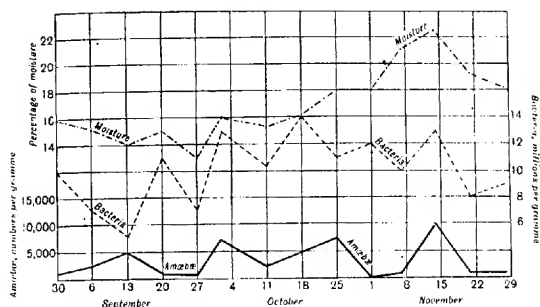


Fig. 4. Great Harpenden Field, August 30—November 29, 1916.

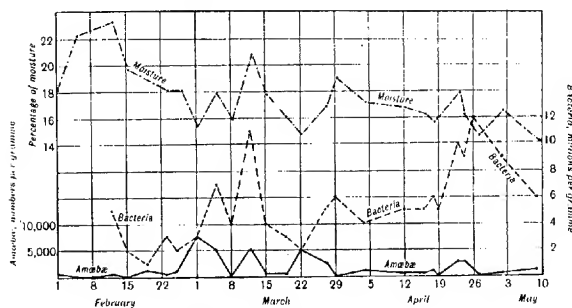


Fig. 5. Broadbalk, Plot 2, February 1—May 10, 1917.

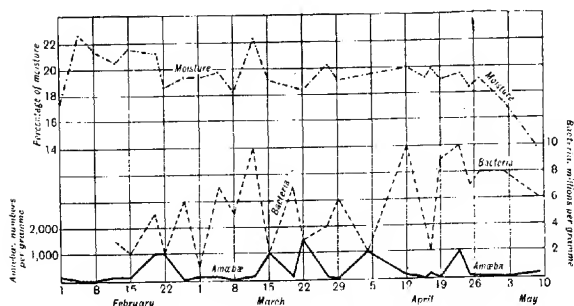


Fig. 6. Great Harpenden Field, February 1—May 10, 1917.

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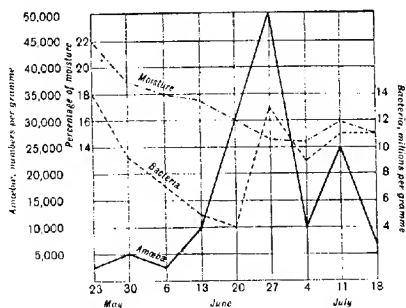


Fig. 7. Broadbalk, Plot 2, May 23—July 18, 1917.

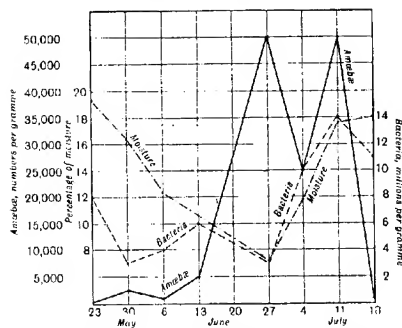


Fig. 8. Great Harpenden Field, May 23—July 18, 1917.

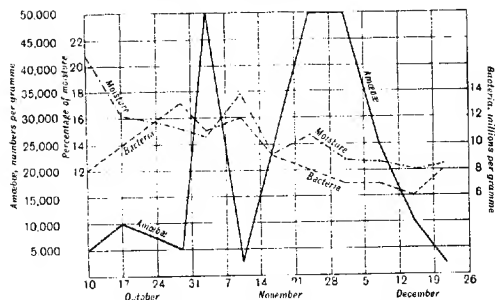


Fig. 9. Broadbalk, Plot 2, October 10—December 21, 1917.

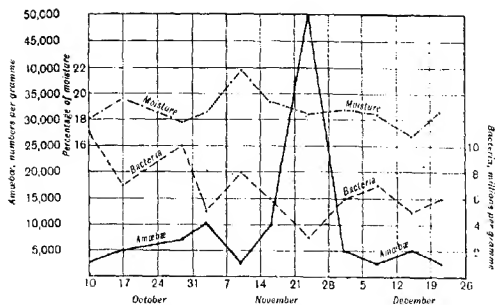


Fig. 10. Great Harpenden Field, October 10—December 21, 1917.

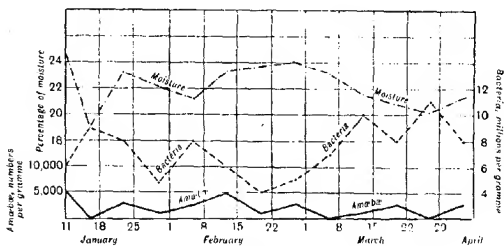


Fig. 11. Broadbalk, Plot 2, January 11—April 4, 1918.

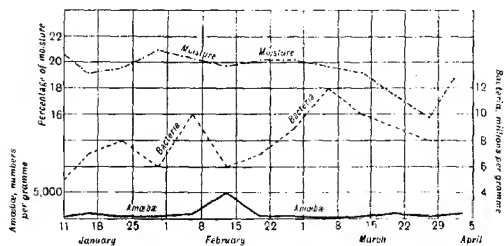


Fig. 12. Great Harpenden Field, January 11—April 4, 1918.

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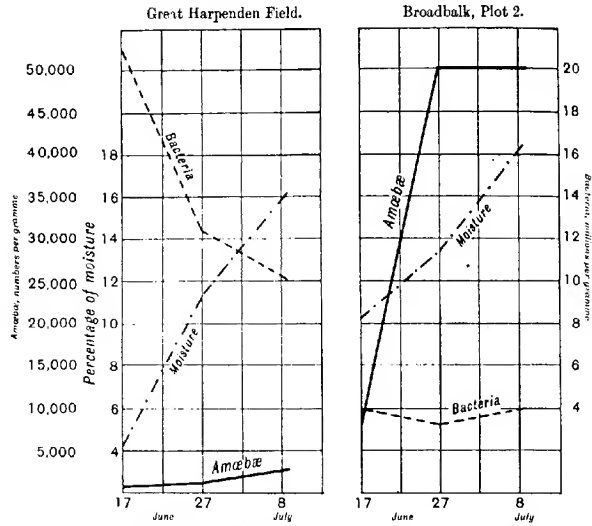


Fig. 13. Great Harpenden Field and Broadbalk, Plot 2, June 17—July 8, 1919.

Curves 14—20 show the temperature and rainfall at various dates from May 10, 1916 to July 9, 1919.

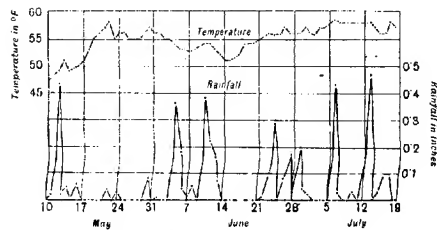


Fig. 14. May 10—July 19, 1916.

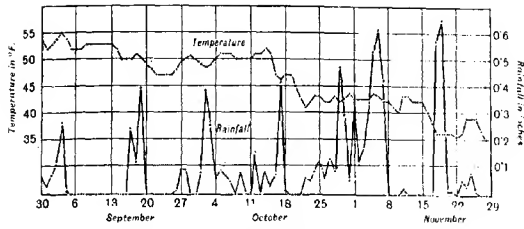


Fig. 15. August 30—November 29, 1916.

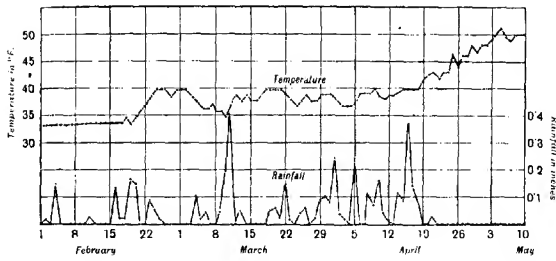


Fig. 16. February 1—May 10, 1917.

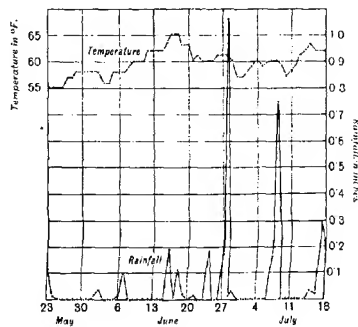


Fig. 17. May 23—July 18, 1917.



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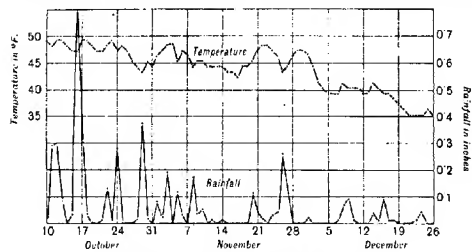


Fig. 18. October 10—December 26, 1917.

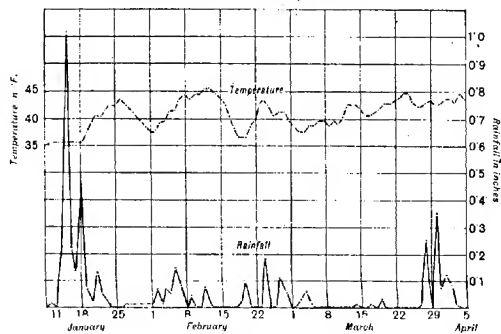
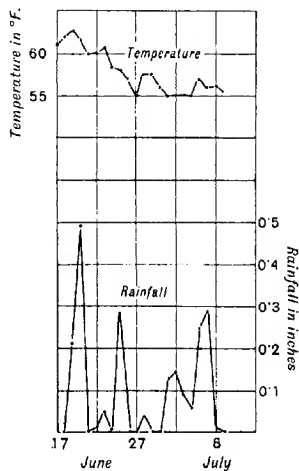


Fig. 19. January 11—April 5, 1918.



# THE INFLUENCE OF CHEMICAL CONSTITUTION ON THE TOXICITY OF ORGANIC COMPOUNDS TO WIREWORMS.

By F. TATTERSFIELD AND A. W. R. ROBERTS.

(Rothamsted Experimental Station.)

(With 18 Diagrams in text.)

THE object of the present investigation was to study the toxic values of a series of organic compounds with respect to wireworms—among the most resistant insects found in the soil—and to correlate as far as possible the toxic values with chemical constitution and physical properties.

In order to obviate the many complexities introduced by soil factors, such as adsorption and decomposition of the added substance, the experiments were carried out in closed flasks containing a known concentration of poison in moist air. The wireworms used were of the genus *Agriotes*.

A certain amount of work has already been done on this problem. Holt(1) operating on the cockroach under somewhat similar conditions concluded that the toxicity of volatile organic compounds increases with the boiling point, though compounds boiling above a certain critical temperature decrease in toxicity as the boiling point rises.

Moore(2) summarises his earlier results as follows:

1. Benzene derivatives are more toxic to the house-fly (*Musca domestica* L.) molecule for molecule than carbon di-sulphide.
2. Physical characters, such as boiling point and vapour pressure, have more influence on toxicity than chemical composition.
3. Up to 250° C. the higher the boiling point the more toxic the compound. Beyond 250° C. the compound is usually so slightly volatile that insufficient evaporates to be effective.

In a later paper(3) these conclusions although slightly modified are generally confirmed.

He states:

1. The toxicity of a volatile organic compound is correlated closely with its volatility, decreasing volatility being accompanied by increased toxicity.

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2. The boiling point is a general index of volatility. Compounds boiling at 225° to 250° C. are usually so slightly volatile that they kill only after long exposure. He suggests that the structure of the respiratory system of the insect may account for the remarkable influence of volatility on toxicity.

In a study of the toxicity of kerosene(4) in the form of emulsions, Moore and Graham ascertained that the high boiling point compounds are more toxic as contact insecticides than the low boiling point compounds.

There is no reason to suppose that the boiling point of a compound can have any intrinsic relationship with its toxicity. It is better to regard it as a measure of some other property or constant associated with the compound: such, for instance, as the vapour pressure or rate of evaporation.

In Moore's later researches and in the present work the value measured is the capacity of an insect to recover from the effects of an exposure of a definite length of time to a known concentration of a poison gas in air. Graham, as Horace T. Brown(6) has recently pointed out, many years ago hazarded the opinion that insects at rest carry on their respiratory processes entirely by diffusion along the tracheae. An insect recovering from the effects of poison vapour is usually in a state of quiescence, and if the tracheal system consisted of a very fine complex of capillaries with impermeable walls the rate of escape of gas or vapour would follow the known laws of diffusion. Moore(5) has, however, recently shown that fumigants may enter and pass through the tracheal walls in vapour form and that slightly volatile compounds may condense upon the tracheal walls and penetrate the chitin rather than evaporate.

In view of the complex nature of the phenomena it is surprising that the relationship existing between the rate of evaporation, volatility or vapour pressure and the toxicity of a compound is as close as it is. There are, however, a number of exceptions resulting from specific physiological effects of the chemical compounds examined.

The rate of diffusion of a vapour out of the tracheal system might be expected to influence its toxicity, and if this be the case there should be a relationship between molecular weight (which determines the rate of diffusion) and toxicity.

In certain series, *e.g.* the hydrocarbons, the toxic values increase with increasing molecular weight, but the rule is by no means rigid. Pseudocumene is more toxic than its isomer, mesitylene; benzyl chloride than the isomeric *o*-chlorotoluene; monomethylaniline than *o*-toluidine.

Benzene, although of a lower molecular weight, is more toxic molecule for molecule than hexane, chloroform, carbon tetrachloride.

Moore lays more stress on volatility than on chemical constitution. A number of instances, however, could be given where toxicity is not determined by volatility. Chloropicrin, carbon di-sulphide, ammonia, hydrocyanic acid are more poisonous than their relatively high volatility would lead one to expect. In the case of ammonia and hydrocyanic acid, Shafer(7) has shown that they become firmly fixed in the tissues of the insect and are not given off when it is removed to fresh air. The solubility in water of these compounds apparently plays an important part in their toxic effect. The marked effect of chemical constitution on toxicity is demonstrated by the increased toxicity consequent on the addition of certain groups to the chain or ring and the fact that isomeric substances are not always equally poisonous. If the addition of a particular group does not increase the reactivity of the compound (*e.g.* methyl group to the benzene ring), the increase in toxicity corresponds with the change in vapour pressure or rate of evaporation. Where, however, the reactivity is altered this is no longer the case. Thus, the hydroxy or amido derivatives are much more reactive than their parent substance, and more toxic than might be expected from the change in their physical properties. Aniline vapour acting upon a wireworm for a sufficient period of time causes a general darkening effect under the chitin: *o*- and *p*-toluidine, but especially mono- and di-methylaniline give rise to intensely dark coloured spots, distributed irregularly within the different segments underneath the chitin. It is well known that aniline and its derivatives under certain conditions change to dark coloured products which may be identical with the compounds of the dianilinoquinone and dianilinoquinone-anil types isolated by Gibbs(8) from old samples of aniline which have undergone slow oxidation. Quinone is known to give rise to red coloured products with proteins and amino acids(9) and it is possible that the dianilinoquinone compounds may behave in the same way. The toxicity of these organic compounds seems to depend primarily on their chemical properties, and only secondarily upon their rates of evaporation.

Shafer(7) showed that the general effect of many insecticides was to depress respiratory activity. Gasoline, carbon di-sulphide and nicotine depress oxygen absorption more than carbon dioxide excretion. In a later research he isolated from the insect body certain reducing, catalysing and oxidising enzymes, and showed that they are deleteriously affected by the insecticides, and that the lipoids of the living oxygen-absorbing

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cells become less permeable to oxygen when impregnated with such vapours as gasoline and chloroform than in their normal condition. Shafer concluded that the action on the enzymes was probably the determining factor in causing death.

Table I. *Toxicity of Isomers.*

Substances.	Mol. wt.	Boiling point ° C.	Of same Toxicity.
			Toxic concentration in millionths of a gm. mol. per 1000 cc. of air.
Xylene ( <i>p</i> )	106	138	230-190
" ( <i>m</i> )	106	138.5	230-185
Toluidine ( <i>o</i> )	107.1	197	8.5-6.5
" ( <i>p</i> )	107.1	200	8.5-6.5
Cresol ( <i>o</i> )	108.1	190.8	9-7.4
" ( <i>p</i> )	108.1	200.5	9-7.4
" ( <i>m</i> )	108.1	201.1	9-7.4
Chlorophenol ( <i>o</i> )	128.5	175-177	6-4
" ( <i>p</i> )	128.5	217	6-4
Substances.	Mol. wt.	Boiling point ° C.	Of Different Toxicity
			Toxic concentration in millionths of a gm. mol. per 1000 cc. of air.
Pseudocumene	120.1	168-170	95-80
Mesitylene	120.1	164	Marginal
Monomethylaniline	107.1	194-195	3.7-2.0
<i>o</i> - and <i>p</i> -toluidine	107.1	197-200	8.5-6.5
Chloraniline ( <i>o</i> )	127.5	208.8	19.0
" ( <i>p</i> )	127.5	232	Marginal
Nitrophenol ( <i>o</i> )	139	—	6.5
" ( <i>p</i> )	139	—	Non-toxic
Benzyl chloride	126.5	176-177	4-3.5
Chlortoluene ( <i>o</i> )	126.5	159-11	120-80
<i>o</i> -di-Cl-benzene	147	179	70-50
<i>p</i> - " "	147	179	Marginal

*Note.* By "marginal" is meant that the substance sometimes acts and sometimes does not. See p. 207.

By toxic concentration is meant the amount in millionths of a gram molecule which when diffused in 1000 cc. of air proves toxic. The higher figure is the death point and the lower the recovery point. Where only one figure is given it means that action is sharp and death occurs.

The experiments detailed in the present paper show that physiological effects are not solely dependent upon any one physical property. Chemical constitution and chemical properties must play the final part, though physical properties determine how far matters can go. The toxic vapour must penetrate into the tracheal system and then through the

walls before it can reach and react with the vital parts of the insect organism. The extent to which it can do this may well depend in no small measure upon the rate at which it can be expelled from these fine tubes after it has once found entrance into them. An insect, therefore, would in general recover more rapidly from the action of a poison which volatilises quickly from its body than from one with a slower rate of evaporation.

The following relationships are brought out in the experiments described in the present paper:

1. The toxicity of isomers is the same in certain cases, but in others it is profoundly affected by the relative position of the groups. A liquid is generally more certain in action than a solid (Table I).

2. Toxicity increases in successive homologues to a certain point, after which it becomes uncertain owing to limitation by the low vapour pressure of the amount of the compound entering into the gaseous phase. This stage is defined as "marginal" in these investigations.

3. The effect of substitution on toxicity varies with the nature of the parent substance, and of the group introduced. The effect of introducing successive  $\text{CH}_3$  groups into the benzene ring is approximately the same, toxicity being about doubled for each substitution; each chlorine atom substituted in the ring increases toxicity three to four times. In these cases the resulting products are about as inert as the parent substance; where this is not the case no such regularity was observed (Table II).

Table II. *Effect of substituting successive methyl groups and chlorine atoms.*

Substance.	Mean toxic concentration*, Millionths of gm. mol. per 1000 cc. of air.	Ratio when highest member = 1.	Factor showing effect of added group.
Benzene	712	8.14	1.8
Toluene	385	4.4	
Xylene	210	2.4	
Pseudocumene	87.5	1.0	2.4
Benzene	712	11.8	3.8
Chlorobenzene	185	3.1	
o-dichlorobenzene	60	1.0	
Toluene	385	3.85	3.85
o-chlorotoluene	100	1.0	

\* Mean of upper and lower (i.e. death and recovery) values.

An OH group had a greater toxic effect when introduced into benzene than when introduced into toluene, while the  $\text{NH}_2$  group had a greater toxic effect in toluene than in benzene (Table III).




204 *Chemical Constitution and Toxicity to Wireworms*Table III. *Effects of OH and NH<sub>2</sub> groups.*

Substance.	Mean toxic concentration.	Ratio.	Factor.
Benzene	712	70	70
Phenol	10.3	1	
Toluene	385	47	
Cresol	8.2	1	47
Benzene	712	30	
Aniline	24.2	1	
Toluene	385	50	50
Toluidine	7.5	1	

4. All vapours having strongly irritant properties possess a marked toxicity. Where substitution produces this effect, a large increase is observed; thus the introduction of chlorine into the toluene side chain giving benzyl chloride, a strongly irritant substance, has a greater influence on toxicity than when introduced into the ring to form non-irritant *o*-chlorotoluene. The substitution of a nitro group into the chloroform molecule or three chlorine atoms into the nitromethane molecule gives rise to chloropicrin, a strongly lachrymatory compound, which is five hundred times as toxic as chloroform, and three hundred times as toxic as nitromethane.

Allyl isothiocyanate, the most toxic substance tested, and the phenols, chlorphenols and ammonia derivatives are all of high toxicity and strongly irritant.

Table IV. *Toxicity of irritant substances.*

Irritant substance. Toxic concentration. Millionths of gm. mol. per 1000 cc. of air.		Non-irritant parent body. Toxic concentration.		Non-irritant isomer. Toxic concentration.
Allyl isothiocyanate $C_3H_5NCS$ 0.75-0.4		—		—
Chloropicrin 2 l $CCl_3NO_2$		Chloroform 1040-800 $CHCl_3$ Nitromethane 710 $CH_3NO_2$		—
Benzyl Chloride 4-3.5 $CH_2Cl$ 		Toluene 420-350 $CH_3$ 		<i>o</i> -chlorotoluene 120-100 $CH_3$ 

5. Certain compounds are particularly poisonous, such as aromatic amido and hydroxy derivatives, the former of these obviously bring about chemical change in the insect body, which is accompanied by the appearance of spots in the hypodermis under the chitin in the case of

monomethylaniline, dimethylaniline, and *o*- and *p*-toluidine, and a general darkening in the case of aniline.

The toxic concentrations in millionths of a gram molecule per 1000 cc. of air are:

Monomethylaniline	...	...	3.7- 2.0
Dimethylaniline	...	...	6.6- 5.0
<i>o</i> -Toluidine	...	...	8.5- 6.5
<i>p</i> -Toluidine	...	...	8.5- 6.5
Aniline	...	...	27-21.5

The phenols possess strongly irritant qualities and as E. A. Cooper (10) has shown exert a de-emulsifying effect upon the colloidal suspension of proteins. The introduction of a CH<sub>3</sub> group slightly, and of NO<sub>2</sub> and Cl groups materially increases the toxicity of these compounds.

Toxic concentration.				
Phenol	...	...	...	10-6-10
<i>o</i> -, <i>m</i> -, <i>p</i> -Cresol	...	...	...	9-7.4
<i>o</i> -nitrophenol	...	...	...	0.5
<i>o</i> -, <i>p</i> -chlorophenol	...	...	...	6-4
di-chlorophenol (1 : 2 : 4)	...	...	...	1.8

#### EXPERIMENTAL.

In all more than seventy-five substances were tested which, while not covering the whole range of simple organic groupings, were representative of the more important and readily obtainable series.

#### *Compounds Tested. (In Groups.)*

HYDROCARBONS.		HALOGEN DERIVATIVES.	
Aliphatic	{ Pentane	Aliphatic	{ Chloroform
	{ Hexane		{ Carbon Tetrachloride
	{ Heptane		{ Dichlorethylene
			{ Trichlorethylene
Aromatic	{ Benzene	Aromatic ring com- pounds	{ Tetrachlorethane
	{ Toluene		{ Bromoform
	<i>m</i> -Xylene		{ Iodoform
	<i>p</i> -Xylene		
	{ Pseudocumene	Aromatic side chain compounds	{ Monochlorobenzene
	{ Mesitylene		{ <i>o</i> - & <i>p</i> -dichlorobenzene
	<i>p</i> -Cymene		{ 1, 2, 4 Trichlorobenzene
	{ Naphthalene		{ <i>o</i> -chlorotoluene
	{ Anthracene		{ Monochloroethylene
	{ Phenanthrene		{ Bromobenzene
			{ Iodobenzene
			{ Benzyl Chloride
			{ Benzal Chloride
			{ Benzotrichloride



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NITRO DERIVATIVES, ETC.		AMINO DERIVATIVES.	
Aliphatic compounds	(Nitromethane Amyl Nitrate Amyl Nitrite)	Aliphatic compounds	(Ammonia Monomethylamine Dimethylamine Trimethylamine Ethylamine)
			(Aniline o- & p-Toluidine Monomethylaniline Dimethylaniline Xylidine α-Naphthylamine Diphenylamine Metaphenylenediamine)
Aromatic compounds	(Nitrobenzene o- & p-Nitrotoluene Nitroxylenes (mixed) Nitronaphthalene Dinitrobenzene)	Aromatic compounds	
HYDROXY DERIVATIVES.		MIXED DERIVATIVES.	
Phenol o- & p- & m-Cresols		o- & p-Chlorophenols 1, 2, 4 dichlorophenol o- & p-Chloronitrobenzene o- & p-Chloraniline o-, m- & p-Nitraniline o- & p-Nitrophenol Trinitrophenol (Picric Acid) Nitrobenzaldehyde Nitrochloroform (Chloropicrin)	
VARIOUS COMPOUNDS.			
Allyl Isothiocyanate Hydrocyanic Acid Pyridine Carbon Disulphide Phenyl Hydrazine			

As the larvae of certain different species of the genus *Agriotes* are not easy to identify, it is probable that two or more species were used: their length ranged from 1.7 cms. to 2.2 cms. We were unable to ascertain definitely whether the size of the insect materially altered its resistance to poison, though in the majority of cases little difference could be found. Larvae tested just prior to the moult were, if anything, rather more resistant and results obtained at this period were therefore discarded.

A number of conical flasks were fitted with lead lined indiarubber stoppers, through each of which ran a glass rod turned up to form a hook at one end. From this hook a small Gooch crucible was suspended by copper wire. The flasks thus set up were carefully calibrated. Three sets of flasks of volume 400, 500-600, and 1150 cc. were used at different times during the experiments. This was done partly for convenience in handling, partly to ascertain whether difference in volume had any material effect upon the results. We were unable to detect any serious difference due to the volume of the flask, but the greater number of the results were finally confirmed in flasks of about 1150 cc. capacity.

The actual mode of operation was as follows: a small pad of filter-paper was put into the perforated Gooch crucible and moistened with 0.1 cc. of distilled water, a necessary addition as wireworms rapidly die from desiccation, and on a hot summer's day 0.1 cc. is about the smallest quantity convenient for handling. One, and sometimes two, wireworms

having been placed in each crucible, known amounts of the substances under investigation were put into the flasks. This was effected in the case of the less volatile substances by weighing out in a suitable dilution in sand, but in the case of the less toxic and more volatile liquids by measuring out the liquid from carefully calibrated capillary pipettes. Some very highly toxic and disagreeable substances like chloropicrin, allyl isothiocyanate, and benzyl chloride were measured out in solution in pentane, which was found to have a negligible toxicity provided its concentration was kept sufficiently low. In the case of the slightly volatile substances the flasks were warmed for a short time on a steam oven to ensure complete volatilisation of the poison and then allowed to cool before the wireworms were put in. The Gooch crucibles containing the wireworms were then rapidly attached to the glass hooks and put into the flasks and the insects allowed to remain in the vapour for a period of 1000 minutes. During this time the flasks remained in a darkened room, the temperature of which usually stood at 15° C., and only varied one or two degrees centigrade throughout the year. After exposure the larvae were taken out and examined, then placed in tubes containing moist sand. They were examined from time to time for a period of eight to ten days, the tubes being for the most part kept in the darkened room. The tests for each substance were repeated a number of times.

On gradually lowering the concentrations of poison in the flasks, it was found that at a certain point death no longer occurred but uncertain results were obtained. Within this zone, which is expressed on the diagrams by dotted lines, the larvae were not killed though they were generally too seriously incapacitated to recover completely. At a lower concentration recovery was complete. The results have been plotted against various constants by means of columns representing the numbers of millionths of gram molecules required either to kill or incapacitate, these points being marked D for death point, I for incapacitation point, R for recovery point. The values obtained are given in Table V.

Toxicity gradually increased in passing from the lower to the higher homologues until a certain member was reached at which uncertain results were obtained, death sometimes occurring and sometimes not, at saturation concentrations. In such cases anaesthesia or narcosis might result, but the larvae were usually capable of recovery. These are listed in Table V as "Marginal and Uncertain." This marginal effect results from the low volatility of the compound, insufficient being evaporated to produce permanent injury except to less resistant insects. These

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marginal substances have fairly high boiling points. Chemically inert substances like the hydrocarbons, certain compounds containing halogens in the ring but boiling above about 170° C., and nearly all organic substances boiling above 215° C., are uncertain in their effects upon

Table V. *Vapours toxic to Wireworms.*

Order of Toxicity measured in Millionths of a Gm. Mol. per 1000 cc. of Air found toxic in 1000 mts. at 15° C.

(The first figure represents death point, second figure represents recovery-point.)						
Of High Toxicity (1-10).	Boiling Point ° C.	Of Moderate Toxicity (10-100).	Boiling Point ° C.	Of Low Toxicity (100-20,000).	Boiling Point ° C.	
Allyl Isothiocyanate ...	0.75-0.4	150.7	Hydrocyanic Acid ...	20-15	26.5	
Chloropicrin ...	2-1	111	<i>o</i> -chloraniline ...	19-0	208.5	
Dichlorophenol (1:2:4) ...	1-8	210	Benzal Chloride ...	24	203-204	
Monomethylaniline ...	3.7-2.0	194-195	Ammonia ...	23-18	-33.5	
Benzyl Chloride ...	4-3.5	176-177	Monomethylamine ...	24-16	-31	
<i>o</i> -Chlorophenol ...	6-4	175-177	Dimethylamine ...	22-16	8	
<i>p</i> -Chlorophenol ...	6-4	217	Ethylamine ...	22-17	16.5	
<i>o</i> -Nitrophenol ...	6-5	214	Nitrobenzene ...	24-16	210.9	
Dimethylaniline ...	6-6.5	193-191	Aniline ...	27-21.5	182	
Xylidine (but with a tendency to be uncertain)	7-5	214-215.5	Trimethylamine ...	40-32	3.5	
			Iodobenzene (incap.)*	50-25	190	
<i>o</i> -Toluidine ...	8.5-6.5	197	Amyl Nitrite ...	64-60	96	
<i>p</i> -Toluidine ...	8.5-6.5	198	<i>o</i> -dichlorobenzene ...	70-50	179	
<i>o</i> -Cresol ...	9-7.4	190	Pyridine ...	76-60	115	
<i>m</i> -Cresol ...	9-7.4	200.5	Pseudocumene ...	95-80	168-170	
<i>p</i> -Cresol ...	9-7.4	201.1	Bromoform ...	94	151	
Phenol ...	10-6-10	181.5	Monobromobenzene ...	96-80	155-156	
Of Low Toxicity (100-20,000).	Boiling Point ° C.	Marginal and Uncertain.	Boiling Point ° C.	Non-Toxic.	Boiling Point ° C.	
Monochlorotoluene ...	120-80	159.4	<i>o</i> -Nitro-Cl-Benzene	243	Anthracene	351
Tetrachlorethane ...	141-60	146-148	<i>o</i> -Nitrotoluene	222	Phenanthrene	340
Amyl Nitrate ...	180-140	148	<i>p</i> -Nitrotoluene	238	Iodoform	—
Monochlorobenzene	200-170	132	Nitroxylene	210-260	Nitrobenzaldehyde	—
Xylene ( <i>p</i> ) ...	230-190	138	Naphthalene	218	Dinitrobenzene	—
Xylene ( <i>m</i> ) ...	230-185	138.5	<i>p</i> -Nitraniline	—	Nitronaphthalene	—
Toluene ...	420-350	111	<i>p</i> -dichlorobenzene	172	<i>p</i> -Nitrophenol	—
Carbon Disulphide	526-400	40	Trichlorobenzene	213	<i>o</i> - & <i>m</i> -Nitraniline	—
Nitromethane ...	710	101	(1:2:4)	—	Trinitrophenol	—
Benzene ...	775-650	80.3	<i>p</i> -Chloraniline	232	(Picric Acid)	—
Heptane ...	800	97	<i>p</i> -Nitro-Cl-Benzene	242	Metaphenylenes	282-28
Chloroform ...	1040-800	61	Mesitylene	164	diamine	—
Carbon Tetrachloride	1600	76.8	<i>p</i> -Cymene	174.5-175.5	Phenyl Hydrazine	245
Trichlorethylene ...	1200	88-89	Benzotrichloride	213	Naphthylamine	300
Hexane ...	3000	71.5	Monochloroxylene	185-192	Diphenylamine	302
Dichlorethylene ...	3100-2400	54.5-56				
Pentane (incap.) ...	16,000	37				

\* The higher concentration incapacitates.

wireworms. Finally, organic compounds boiling above  $240^{\circ}\text{C}$ . have too low a volatility to produce any effect upon wireworms and are listed as *non-toxic* (see Table V).

#### THE HYDROCARBON SERIES.

The hydrocarbons have been extensively used as insecticides in the form of petroleum and various fractions obtained by the distillation of coal tar. Only three members of the aliphatic series were tested, pentane, hexane and heptane—the normal straight chain compounds being used in each case; the results obtained are shown in Diagram 1.

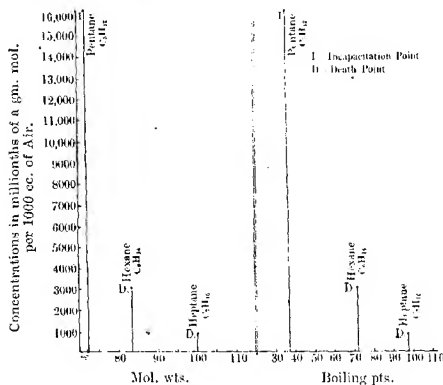


Diagram 1. Aliphatic Hydrocarbons showing relationship between Toxicity and Molecular Weights and Boiling Points.

Pentane, the rate of evaporation of which is extremely rapid, was scarcely toxic, incapacitation only occurring even at high concentration. Diagram 1 shows that toxicity increases in passing from members with less molecular weight and low boiling point to those of higher. At the time of these experiments it was not possible to obtain higher members than heptane, but from the nature of the substances it would seem justifiable to conclude that toxicity would further increase until volatility became too low.

An analogous series is found in the aromatic hydrocarbons, the amounts required to kill steadily decreasing from benzene to toluene, to *m*- and *p*-xylene until pseudocumene is reached (see Diagrams 2 and 3).

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Mesitylene, *p*-cymene and naphthalene were found to be marginal and uncertain and the results given by them are indicated by the broken lines running across the diagrams.

Table VI. *Hydrocarbon Series.*  
Toxic concentrations and physical properties.

Toxicity.	Substance.	Mol. wt.	Boiling point °C.	Vapour pressure at 15° C.	Wts per 1000 cc. of Air at 15° C. found toxic.	Nos. of millionths of a gm. mol. per 1000 cc. of Air at 15° C. found toxic.
Low Toxicity	Pentane (normal)	72.1	37	345 mm.	1.2	16,600 (I.)
	Hexane "	86.1	71	96 "	.26	3000
	Heptane "	100.1	97	27 "	.08	800
Low Toxicity	Benzene	78	80.3	58.9 "	.060-.0507	775-650
	Toluene	92	111	17.2 "	.0386-.0322	420-350
	Xylene ( <i>m</i> )	106.1	138.5	4.74 "	.0244-.0196	230-185
	Xylene ( <i>p</i> )	106.1	138	13.69 "	.0244-.0204	230-190
Moderate	Pseudocumene	120	168-170	7.75 "	.0114-.0096	95-80
Marginal	Mesitylene	120	164	23.53 "	Marginal	Marginal
	Para-Cymene	134	174.5-175.5	5.71 "	"	"
	Naphthalene	128	218	.062 (Allen)	"	"
Non-Toxic	Anthracene	178	351	—	Non-Toxic	Non-Toxic
	Phenanthrene	178	340	—	"	"

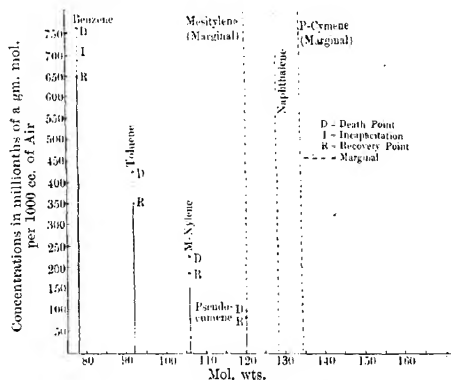


Diagram 2. Aromatic Hydrocarbons showing relationship between Toxicity and Molecular Weights.

Diagrams 4 and 5 show the results plotted against vapour pressures. No. 4 gives results obtained with benzene derivatives on a rather larger scale. The vapour pressure values are taken from tables given by Woringer (*Zeit. physik. Chemie.*, 34, 1900, pp. 262-263) and by Young. No. 5 shows a wider range of compounds (halogen derivatives of benzene being included). The marginal compounds mesitylene and *p*-cymene are omitted from this graph.

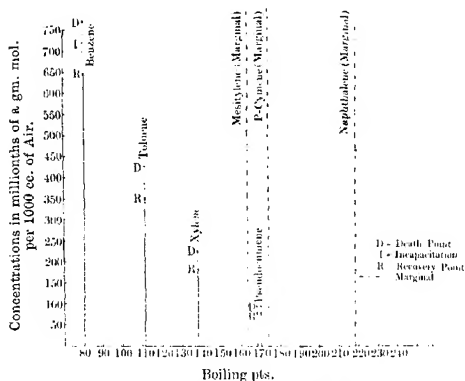


Diagram 3. Aromatic Hydrocarbons showing relationship between Toxicity and Boiling Points.

An examination of these diagrams shows, with certain exceptions, that as the vapour pressure decreases there is an increase in toxicity. Benzene, however, is found to be more toxic than the straight chain hydrocarbon, hexane, containing six carbon atoms, and somewhat more toxic than heptane, indicating that the ring structure adds slightly to the toxic value. Two serious exceptions occur in the case of meta-xylene and mesitylene. If vapour pressure were the chief determining factor meta-xylene with a pressure of 4.74 mm. should be more toxic than pseudocumene with 7.75 mm. This is not the case. Mesitylene with 23.5 mm. should be slightly less poisonous than toluene, but its toxicity is almost nil under our experimental conditions. The vapour pressures of some of the compounds used in this investigation have already been determined, but in view of the great difficulty of purifying some of the compounds and of the marked effect of traces of impurity on the physical

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constants, it is by no means safe to assume that the published values hold for the specimens actually used in our experiments. The rates of evaporation of a number of the compounds were therefore determined.

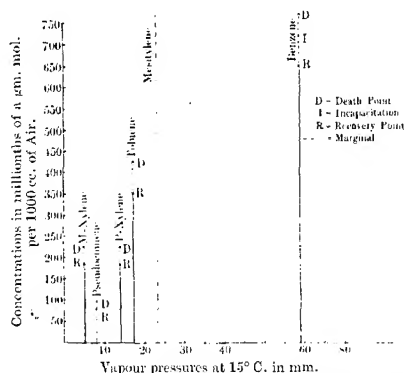


Diagram 4. Aromatic Hydrocarbons showing relationship between Toxicity and Vapour Pressures.

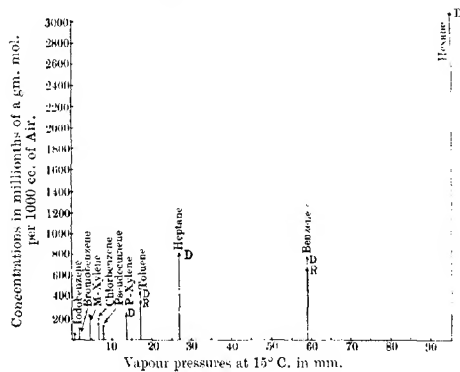


Diagram 5. Showing relationship between Vapour Pressures and Toxicity.

The method employed is described and the results obtained indicated later (p. 229). Reference to Table XV and Diagram 17 shows that

*m*-xylene (carefully purified by the sulphonation process) was considerably more volatile than pseudocumene used in these experiments, and also that both the mesitylene and para-cymene were molecule for molecule rather less volatile than the pseudocumene used. This difference in volatility seems to account for the observed differences in toxicity, and explains why wireworms recover more readily from *m*-xylene than they do from pseudocumene, while the *p*-cymene and mesitylene used by us would appear to have a volatility just too low to give a sufficient concentration of vapour in our flasks to produce death or permanent injury. The difference in toxicity between mesitylene and pseudocumene, the volatilities of which are very near together, may however be the result of different molecular arrangement.

#### HALOGEN DERIVATIVES.

Halogen derivatives of the aliphatic series are of comparatively low toxicity, which may be accounted for by their volatile nature. When plotted to molecular weights no simple regularity appears, but when plotted to boiling points a gradual increase in toxicity is observable as the boiling points increase. An exception to the rule is found in the case of chloroform; it is possible that this substance may undergo some decomposition in the organism. Old samples of chloroform were found to be slightly more poisonous than new samples; in these experiments, therefore, only best quality anaesthetic chloroform, free from free chlorine and chlorides, and carefully washed with water, was used. Most of these substances are less toxic than carbon disulphide.

Table VII. *Aliphatic Halogen Derivatives.*

	Substance.	Mol. wt.	Boiling Point°C.	Vapour Pressure at 15°C.		Nos. of millionths of a gm. mol. per 1000 cc. of air at 15°C. found toxic.
				mm.	grams per 1000 cc. of air at 15°C. found toxic.	
Low Toxicity	Dichlorethylene	97	54.5-56	—	.30-.23	3100-2400
	Trichlorethylene	131.4	88-89	—	.158	1200
	Carbon Tetrachloride	153.8	76.8	72	.246	1600
	Chloroform	119.4	61	128	.124-.0935	1040-800
Moderate T.	Tetrachlorethane	167.9	146-148	—	.0237-.0100	141-60
	Bromoform	252.8	151	—	.0238	94
Non-Toxic	Iodoform	393.8	—	—	—	Non-Toxic

Diagrams 8 and 9 show the effects of the aromatic halogen derivatives. The substitution of chlorine in the hydrocarbon ring appears to have an



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approximately constant effect, monochlorobenzene being about 3.8 times as toxic as benzene, *o*-dichlorobenzene about three times as toxic as the monochlor derivative, while *o*-chlortoluene is 3.5 times as toxic as

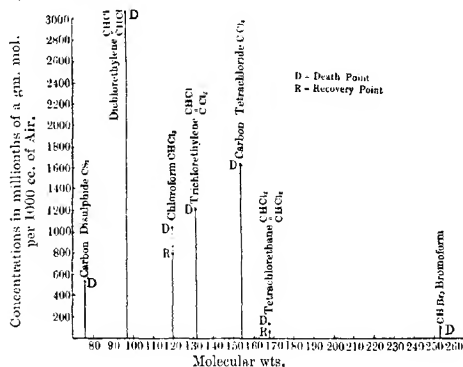


Diagram 6.  $CS_2$  and Aliphatic Chlorine derivatives showing relationship between Toxicity and Molecular Weights.

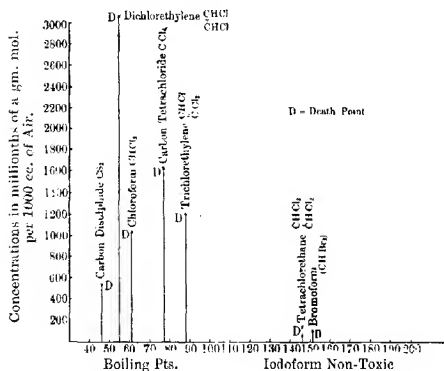


Diagram 7.  $CS_2$  and Aliphatic Chlorine derivatives showing relationship between Toxicity and Boiling Points

toluene. Para-dichlorobenzene however at saturation doses only produced anaesthesia from which the majority of the larvae recovered. Benzyl

chloride, with chlorine in the side chain and which gives off a very irritant vapour, was more toxic than the isomeric *o*-chlorotoluene with chlorine in the ring. Brombenzene and iodobenzene were toxic only at doses representing the saturation points for these compounds.

Table VIII. *Aromatic Halogen Derivatives.*

Toxicity.	Substance.	Mol.wt.	Boiling Point °C.	Vapour Pressure at 15° C.	Wts in grams per 1000 cc. of Air at 15° C. found toxic.	Nos. of millionths of a gm. mol. per 1000 cc. of Air at 15° C. found toxic.
Low	Monochlorobenzene	112.5	132	6.75	.0225-.0191	200-170
	<i>o</i> -chlorotoluene	126.5	159.4	—	.0152-.01	120-80
Moderate	Monobrombenzene	157	155-156.5	1.55	.015-.0125	96-80
	<i>o</i> -dichlorobenzene	147	179	—	.0102-.007	70-50
	Iodobenzene	204	190	0.65	.010-.005	50-25
	Benzalchloride	161	203-204.5	—	.00386	24
High	Benzylchloride	126.5	176-177	—	.0005-.00044	4-3.5
	<i>p</i> -dichlorobenzene	147	172	—	—	—
Marginal	1:2:4 trichlorobenzene	181.4	213	—	—	—
	Monochloroxylene	140.5	185-192	—	—	—
	Benzotrichloride	195.5	213-216	—	—	—

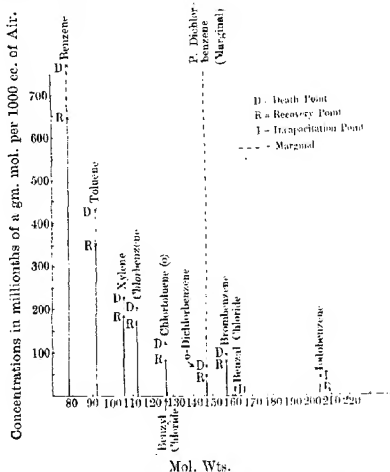


Diagram 8. Aromatic Hydrocarbons and Chlorine derivatives showing relationship between Toxicity and Molecular Weights

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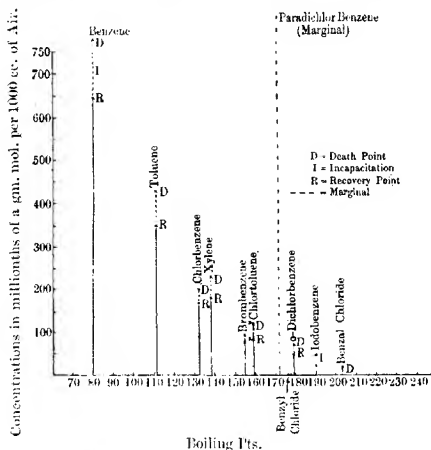


Diagram 9. Aromatic Chlorine derivatives showing relationship between Toxicity and Boiling Points.

### AROMATIC HYDROXY DERIVATIVES.

Table IX. *Aromatic Hydroxy Derivatives.*

Toxicity.	Substance.	Mol. wt.	Boiling Point °C.	Wts in grams per 1000 cc. of Air at 15° C. found toxic.	Nos. of millionths of a gm. mol. per 1000 cc. of Air at 15° C. found toxic.
High	Phenol	94	181.5	0.001-0.009	10-6-10
	<i>o</i> -Cresol	108	190	0.00097-0.008	9-7-4
	<i>m</i> -Cresol	108	200.5	0.00097-0.008	9-7-4
	<i>p</i> -Cresol	108	201.1	0.00097-0.008	9-7-4
	<i>o</i> -Nitrophenol	139	214	0.009	6-5
	<i>o</i> -Chlorophenol	128.5	175-177	0.0077-0.005	6-4
	<i>p</i> -Chlorophenol	128.5	217	0.0077-0.005	6-4
	Dichlorophenol (1:2:4)	163	210	0.003	1-8
Non-Toxic	<i>p</i> -Nitrophenol	139	—	—	—
	Trinitrophenol (Picric Acid)	229	—	—	—

This group was found to be highly poisonous. The introduction of a methyl group into phenol only slightly raised its toxicity, the proportional effect being much less than that due to its introduction into benzene and toluene. The position in the ring was practically without

effect, the three isomeric cresols being equally poisonous. The introduction of chlorine atoms had also a slightly less effect upon the toxicity of phenol than it had upon benzene, and again no difference could be detected in the values for the isomeric *o*- and *p*-chlorphenols, despite their considerable differences in boiling point. The introduction of two chlorine atoms forming 1:2:4 dichlorphenol gave rise to one of the most toxic products tested, this compound being more than five times as poisonous as its parent substance.

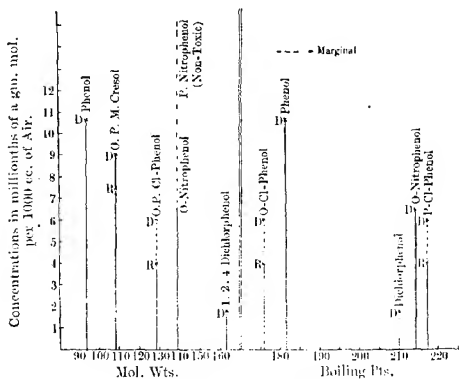


Diagram 10. Phenols. Effect of substitution in ring.

The introduction of a nitro group shows the effect of position, the ortho derivative being more toxic than phenol, while the para compound, which however is only slightly volatile, was non-poisonous.

The effect of substitution upon benzene and toluene are put in for purpose of comparison (Table X).

The toxicity of these compounds may be due to their irritant qualities, or to chemical or physical change induced in the organism. E. A. Cooper<sup>(10)</sup> has shown that phenol precipitates suspensions of proteins, and both germicidal and insecticidal effect may depend in no small measure upon this property.

It is of interest to compare these results with those obtained by Cooper, by Rapp and by Bechhold and Ehrlich on the bactericidal properties of the substituted phenols. Cooper<sup>(10)</sup> has shown that the introduction of  $\text{NO}_2$  groups and of a  $\text{CH}_3$  group increases both the

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germicide and protein precipitating power of this group of substances. Our experiments indicate a similar but smaller increase in larvicidal power. The isomeric chlorphenols were found by Rapp<sup>(11)</sup> to be more toxic to bacteria than the cresols. Bechhold and Erlich<sup>(12)</sup> showed that toxicity to certain pathogenic bacteria depends on the number of halogen atoms introduced and while the first chlorine atom lowers toxicity, further substitution increases it. Our results indicate a consistent increase in toxicity, but a second chlorine atom had a slightly greater effect than the first.

Table X. *Mean Toxicity of Phenol Derivatives, showing effect of substitution.*

In Millionths of a Gram-Molecule per 1000 cc. of Air.

Effect of OH Group.			Effect of CH <sub>3</sub> Group.		
Substance	Toxicity mean	Ratio	Substance	Toxicity mean	Ratio
{ Benzene	712	70	{ Benzene	712	1.8
{ Phenol	10.3	1	{ Toluene	385	1
{ Toluene	385	47	{ Phenol	10.3	1.25
{ Cresol	8.2	1	{ Cresol	8.2	1

Effect of Cl Group.			Effect of Nitro Group.		
Substance	Toxicity mean	Ratio	Substance	Toxicity mean	Ratio
{ Benzene	712	3.8	{ Benzene	712	35.6
{ Chlorobenzene	185	1	{ Nitrobenzene	20	1
{ Chlorobenzene	185	3.1	{ Phenol	10.3	1.6
{ Dichlorobenzene 1 : 2	60	1	{ o-Nitrophenol	6.5	1
{ Phenol	10.3	2	—	—	—
{ Monochlorophenol	5	1	—	—	—
{ Chlorophenol	5	2.8	—	—	—
{ Dichlorophenol 1 : 2 : 4	1.8	1	—	—	—

### NITRO DERIVATIVES AND MIXED NITRO DERIVATIVES.

Nitrobenzene was found to have considerable toxicity, its toxic value however corresponded very closely to the saturation point. Nitrotoluene and nitroxylene were so slightly volatile that their effects were uncertain, while nitronaphthalene produced no effect whatever.

Attempts were made to increase the toxicity of the nitro derivatives by the addition of certain chemical groups. A careful study was made of the toxic relationship existing between nitromethane, chloroform and nitrochloroform (chloropicrin). The results are indicated on Diagram 12.

Chloropierin in constitution can be regarded as derived from chloroform and nitromethane. Its properties, however, are unlike those of either of its parent substances. It is a liquid which gives off an extremely irritant and lachrymatory vapour. While both nitromethane and chloroform have very slight poisonous properties, the poisonous nature of this compound to insects is intense, being at least 500 times greater than that of chloroform and 350 times greater than that of nitromethane.

Table XI. *Nitro Derivatives.*

Toxicity.	Substance.	Mol. wt.	Boiling point <sup>2</sup> (°C.)	Wts in grams per 1000 cc. of Air at 15° C. found toxic.	Nos. of millionths of a gm. mol. per 1000 cc. of Air at 15° C. found toxic.
Low	Nitromethane	61	101	·0433	710
	(Amyl Nitrate	133	148	·0239-·0186	180-140
	(Amyl Nitrite	117	96	·0075-·007	64-60
Moderate	Nitrobenzene	123	210·9	·00295-·002	24-16
High	<i>o</i> -nitrophenol	139	214	·0009	6·5
	Nitrochloroform (Chloropierin)	164·5	111	·00033-·00016	2-1
	<i>o</i> -Nitrochlorobenzene	157·5	243	—	—
Marginal	<i>o</i> -Nitrotoluene	137	159·4	—	—
	<i>p</i> -Nitrotoluene	137	162·3	—	—
	Nitroxylene (mixed deriva.)	151	240-260	—	—
	<i>p</i> -Nitraniline	138	—	—	—
	<i>p</i> -Nitrochlorobenzene	157·5	242	—	—
	Nitrobenzaldehyde	151	—	—	—
	Dinitrobenzene	168	—	—	—
Non-Toxic	Nitronaphthalene	173	—	—	—
	<i>p</i> -Nitrophenol	139	—	—	—
	<i>o</i> -Nitraniline	138	—	—	—
	<i>m</i> -Nitraniline	138	—	—	—

The introduction of chlorine, together with a nitro group, into the benzene ring was studied. The nitrochlorobenzene products have an irritant action, and it was thought probable that toxicity would be high, while the difficulty of handling, characteristic of chloropierin, would be small. *o*- and *p*-chloronitrobenzene, chlordinitrobenzene and dichloronitrobenzene were tested. It is probable that the intrinsic toxicity of these compounds is great, but their vapour pressure and therefore the amounts entering the vapour phase is so low as to render them uncertain or non-toxic in effect. For example *o*-chloronitrobenzene might kill at a concentration of 5 millionths of a gram-molecule in 1000 minutes, but its action was uncertain and some larvae recovered from saturation doses

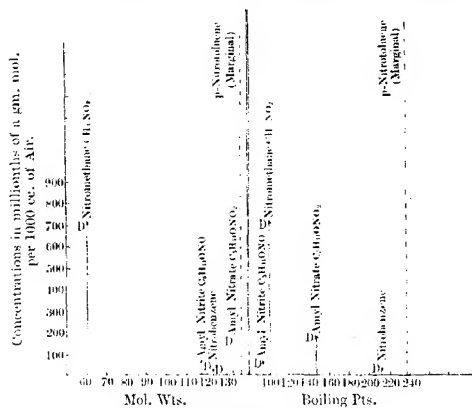


Diagram 11. Various Nitro derivatives.

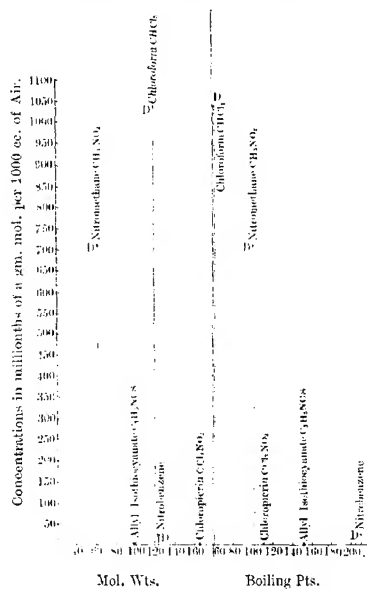


Diagram 19. Effect of mixed groupings.

of this material. All other mixed nitro derivatives except *o*-nitrophenol were of low toxicity for the same reason.

#### AMINO DERIVATIVES.

Ammonia and its aliphatic derivatives were added to the flasks in aqueous solution (1 per cent.) and it was immediately obvious that the added water might have a serious effect upon the results, as some of these compounds are not readily liberated quantitatively from their solutions. In order to effect this liberation a calculated quantity of freshly ignited lime was added to the flasks, in amount slightly in excess

Table XII. *Amino Derivatives.*

(Aliphatic.)					
Toxicity.	Substance.	Mol. wt.	Boiling point °C.	Wts in grams per 1000 cc. of Air at 15° C. found toxic.	Nos. of millionths of a gm. mol. per 1000 cc. of Air at 15° C. found toxic.
Moderate	Trimethylamine	59	3.5	.0024-.0019	40-32
	Ethylamine	45	16.5	.001-.00075	22-17
	Dimethylamine	45	8	.001-.0072	22-16
	Monomethylamine	31	-6	.00075-.0005	24-16
	Ammonia	17	-33.5	.0004-.0003	23-18
(Aromatic.)					
Moderate	Pyridine	79	115	.006-.0017	76-60
	Aniline	93	182	.0025-.002	27-21.5
	<i>o</i> -chloraniline	127.5	208.8	.0024	19
	<i>o</i> -Toluidine	107.1	197	.0009-.0007	8.5-6.5
	<i>p</i> -Toluidine	107.1	198	.0009-.0007	8.5-6.5
High	Xylidine	121	214.5-215.5	.00085-.0006	7-5
	Dimethylaniline	121	193-194	.0008-.0006	6-6.5
	Monomethylaniline	107.1	194-195	.0004-.0002	3.7-2.0
	<i>p</i> -Nitraniline	138	—	—	—
Marginal	<i>p</i> -chloraniline	127.5	232	—	—
	<i>o</i> - and <i>m</i> -Nitraniline	138.1	—	—	—
	Metaphenylenediamine	108.1	282-284	—	—
Non-Toxic	Phenyldiazine	117	243.5	—	—
	Naphthylamine	143	300	—	—
	Diphenylamine	169.1	302	—	—

of that required to unite with the added water, but not sufficient to cause complete dehydration of the wet pads in the crucible. The flasks were then closed, heated for some time in the oven and after cooling for some hours the Gooch crucibles with the larvae were rapidly put in. A careful test was made to ascertain the effect of the amount of moisture



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on the pad in the Gooch crucibles. Lowering this from 0.1 cc. to 0.02 cc. had scarcely any effect upon the toxicity of ammonia, while the toxic values of mono- and di-methylamine were only slightly raised.

The results are shown on Diagram 13.

Ammonia, ethylamine and monodimethylamine have about the same toxic values, molecule for molecule, while trimethylamine is slightly less poisonous. Ammonia is found to be very poisonous to wireworms when actual weights and not gram molecular weights are considered, so small a quantity as 0.4 mg. per 1000 cc. of air being fatal.

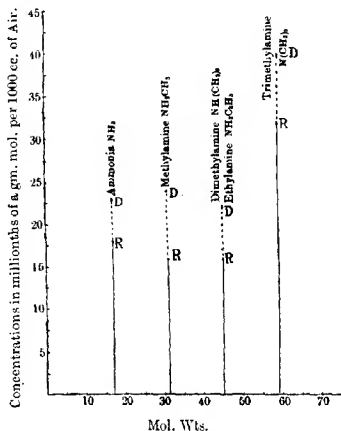


Diagram 13. Ammonia Series.

The results for these substances are calculated from the formulae of the gases rather than their hydrates, the toxicities however indicate that the solubilities of these compounds, and the readiness with which they are absorbed, play an active part in determining their toxicity.

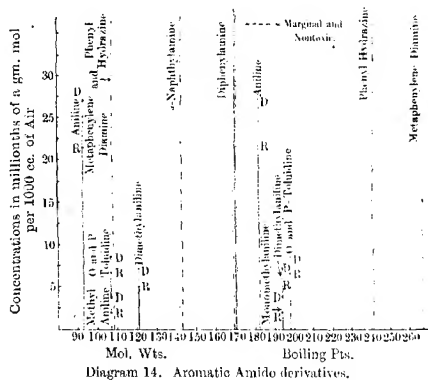
Reference to Diagram 14 shows aniline is of the same order of toxicity as ammonia. The effect on toxicity of reducing the  $\text{NO}_2$  group of nitrobenzene to  $\text{NH}_2$  is very slight, despite the great change in chemical properties. The effect of introducing a methyl group in the ring, giving *o*- and *p*-toluidine, is to increase toxicity threefold, its attachment to the nitrogen in monomethylaniline increases toxicity still further, this

compound under the condition of our experiments being six to seven times as toxic as aniline.

These results differ from those obtained by Foreman and Graham Smith(13) who found that the hydrochlorides of *o*-toluidine and monomethylaniline were equally effective as stomach poisons to house flies as aniline-hydrochloride, while *p*-toluidine hydrochloride was non-toxic.

A sample of xylydine distilling between 214° and 215.5° C. showed some uncertainty and all derivatives of this group boiling at temperatures higher than this were either marginal or non-poisonous.


From the spotting effect produced by these compounds, chemical change is obviously playing a preponderating part in their toxic action.



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was less toxic to *B. Typhosus* than these higher aliphatic amines and than carbolic acid, while ortho- and para-toluidine were more toxic than aniline. Pyridine was found to be the most feeble in its germicidal action of all the monacidic amines tested. A tentative explanation offered by these investigators for the high germicidal efficiency of the aliphatic as contrasted with the aromatic amines is that it may be due to the presence in aqueous solution of hydroxyl ions liberated through ionisation of alkyl ammonium hydroxide, but that this is not entirely satisfactory is indicated by the low germicidal power of ethylenediamine, which is a strong base. They point out that the replacement of hydrogen in ammonia by radicles of an acidic nature such as phenyl, tolyl, succinyl groups gives rise to substances with feeble germicidal action. Although there is no strict analogy between the results obtained by us for the insecticidal power of these compounds and their germicidal action, there is a parallelism. Pyridine was found to be less potent as an insecticide than any other of the organic bases tested, while all the aliphatic amines had weight for weight a greater toxicity than aniline. Toluidine had also a greater toxic action than aniline.

Table XIII. *Effect of NH<sub>2</sub> group and comparison with effect on bacteria.*

Substance.	Formulae.	Mol. wt.	Toxicity in mil. lionths of gm. mol. per 1000 cc. Air (to wireworms).	Toxicity in gms per 1000 cc. Air (to wireworms).	Carbolic coef. to <i>B. Typhosus</i> (Morgan and Cooper).
Toluidine <i>o, p</i>	$\text{CH}_3 \text{C}_6\text{H}_4 \text{NH}_2$	107	8.5-9.5	.0009-.0007	$\left\{ \begin{array}{l} o \ 1.0 \\ m \ 1.3 \\ p \ 1.25 \end{array} \right.$
Ethylamine	$\text{NH}_2 \text{C}_2\text{H}_5$	45	22-17	.001-.00075	
Aniline	$\text{C}_6\text{H}_5 \text{NH}_2$	93	27-21.5	.0025-.002	
Pyridine		79	76-60	.006-.0047	0.18

The toxicity of the lower amines to insects might be accounted for by the ionisation of the alkyl ammonium hydroxides, but between the chemical action of the aliphatic and aromatic amines there is an obvious difference, the aliphatic amines giving rise to no darkening and spotting such as is produced by the aromatic amines. It would appear probable that the oxygen absorbing capacity of the aromatic amido derivatives and their conversion into compounds of the quinone type is playing a large part in their toxic action.

All the amines which boiled above 215° C. were either marginal or non-toxic; thus *p*-nitraniline and *p*-chloraniline were uncertain in action,

while *o*- and *m*-nitraniline, *m*-phenylenediamine, phenylhydrazine, naphthylamine and diphenylamine were non-toxic.

#### MISCELLANEOUS GROUP.

Carbon disulphide, hydrocyanic acid, allyl isothiocyanate were tested for the purpose of comparison with the compounds of other groups. The first two of these compounds have been widely used as insecticides. Carbon disulphide was only slightly poisonous, being of the same order of toxicity as benzene. Hydrocyanic acid was of considerable toxicity when toxic concentration by weight was considered, 0.5 to 0.3 mg. per 1000 cc. of air being fatal. Allyl isothiocyanate was the most toxic product tested.

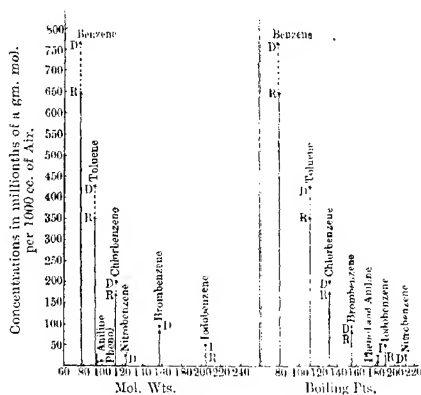


Diagram 15. Effect of Addition of Groups to Benzene Ring.

Diagrams 15 and 16 indicate the toxic effect of adding various groups to the benzene and toluene rings. The effect of substitution depends upon the nature of the resulting product and this varies with the group introduced. The proportional effect brought about by the substitution of any particular group is also dependent upon the nature of the chain or ring into which it is introduced.

An examination of Table XIV shows a wide variation in results in toxic values according to the groups introduced. In the hydrocarbon ring the effect of introducing successive methyl or chlorine groups is fairly constant provided substitution takes place in the ring, that of the

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former group is to double toxicity approximately, while the introduction of chlorine into the ring multiplies toxicity three to four times. If chlorine is introduced into the side chain to give benzyl chloride, the toxicity is multiplied a hundred-fold.

The effect of the various groups when introduced singly into the benzene ring is in order of magnitude as follows

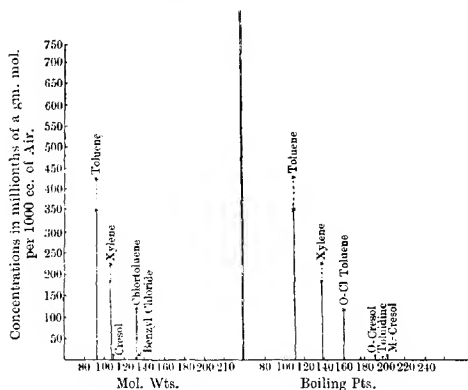
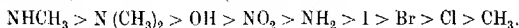




















Diagram 16. Effect of Addition of Groups to Toluene.

The presence in the ring of other substituents seriously modifies this order. When a methyl group has been introduced to form toluene the order becomes Cl (side chain) >  $\text{NH}_2$  > OH > Cl (ring) >  $\text{CH}_3$ . Again the proportional increase in toxic action due to the introduction of one  $\text{CH}_3$  group into phenol is less than when substituted into benzene; in the case of aniline it is considerably greater if introduced into the ring, and still greater if attached to the amido group. So also the effect of chlorine upon the toxic action of phenol is slightly less than upon that of benzene.

The mutual effect of subsidiary groups in the main ring or chain is of fundamental importance, combinations such as that of chlorine and hydroxy groups, of methyl and amido groups in the benzene ring giving rise to compounds of a high toxicity to wireworms, while the association of chlorine and methyl groups is not so effective unless the chlorine is directly attached to the methyl group.


























Table XIV. *Toxic Effect of Substitution into various Rings.*

Toxicity in millionths of a gm. mol. per 1000 cc. Air.

Kind of Chain	Formula.	Substituent.	Toxic Concentration of Parent Compound. A.	Resulting Product.	Formula.	Toxic Concentration of Resulting Product. B.	Ratio of Toxic concentrations of derivative and parent substance. A : B.
alkane	$C_5H_{12}$	$CH_3$	16,600	Hexane	$C_6H_{14}$	3000	5.5
alkane	$C_6H_{14}$	"	3,000	Heptane	$C_7H_{16}$	800	3.75
aromatic	$C_6H_6$	"	775-650	Toluene		420-350	1.83-1.86
aromatic		"	420-350	<i>m</i> -Xylene		230-185	1.8-1.9
				<i>p</i> -Xylene		230-190	1.8
aromatic		"	230-190	Pseudocumene		95-80	2.4
aromatic		"	10.6-10	Cresol <i>o</i> , <i>m</i> and <i>p</i>		etc. 9-7.4	1.18-1.35
aromatic		"	27-21.5	Toluidine <i>o</i> and <i>p</i>		8.5-6.5	3.17-3.3
	"	"	"	Monomethyl-aniline		3.7-2.0	7.3-10.7
aromatic	"	"	8.5-6.5	Xylidine		7-5	1.2-1.3
aromatic		"	3.7-2.0	Dimethylaniline		6.6-5	0.56-0.4
aromatic	$NHCH_3$	"	23-18	Monomethylamine	$N(CH_3)_2$	24-16	1 (Approx.)
aromatic	$NH_2$	"	24-16	Dimethylamine	$NH(CH_3)_2$	22	1 "
aromatic	$NH_2$	"	22	Trimethylamine	$N(CH_3)_3$	40-32	0.55-0.7 (Approx.)
aromatic	$NH_2$	$C_2H_5$	23-18	Ethylamine	$NH_2(C_2H_5)$	22-17	1 (Approx.)
aromatic		Cl	775-650	Cl-Benzene		200-170	3.87-3.82
aromatic		"	200-170	Di-Cl-Benzene ( <i>m</i> )		70-50	2.86-3.4

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Table XIV (*continued*).

Ring or Chain.	Formula.	Substi- tuent.	Toxic Concen- tration of Parent Compound. A.	Resulting Product.	Formula.	Toxic Con- centration of Resulting Product. B.	Ratio of Toxic Concentrations derivative of parent subst. A B.
Toluene		Cl	420-350	<i>o</i> -Cl-Toluene		120-80	3.5-4.3
"	"	"	"	Benzyl Chloride		4-3.5	105-100
Benzyl Chloride		"	4-3.5	Benzal Chloride		24	0-17
Aniline		"	27-21.5	Chloraniline		19	1-4
Phenol		"	10-6-10	<i>o</i> - and <i>p</i> -Cl-Phenol	 & 	6-4	1.7-2.5
Chlorophenol ( <i>o</i> - and <i>p</i> -)	 & 	"	6-4	1:2:4 di-Cl-Phenol		1-8	3-3
Benzene		Br	775-650	Brombenzene		96-80	8
"	"	I	"	Iodobenzene		50-25	15.5-26
"	"	OH	775-650	Phenol		10-6-10	73-65
Toluene		"	420-350	Cresol ( <i>o</i> , <i>m</i> , <i>p</i> )	 etc.	9-7.4	46-47
Benzene		NO <sub>2</sub>	775-650	Nitrobenzene		24-16	32-40
Phenol		NO <sub>2</sub>	10-6-10	<i>o</i> -Nitrophenol		6-5	1.6-1.5
Benzene		NH <sub>2</sub>	775-650	Aniline		27-21.5	28.7-30

The association of chlorine and nitro groups gives rise to highly toxic compounds. This is particularly noticeable in the case of chloropicrin, which is not only very volatile but also excessively poisonous. When these two groups are brought together in the benzene nucleus the toxicity is limited by the low volatility of the resultant product. This factor also limits the poisonous properties of many other combinations such as the nitro amido, nitro aldehyde, di nitro groups, the resulting products being too slightly volatile to allow their vapours to produce a permanently injurious effect.

#### RATE OF EVAPORATION AND TOXICITY.

The rate of evaporation of a number of the substances actually used in the foregoing experiments was determined for the purposes of correlation with toxicity (this course being rendered necessary by the profound influence of traces of impurity upon vapour pressures). The method adopted was as follows: straight walled tubes 3.5 cms. in length and

Table XV.

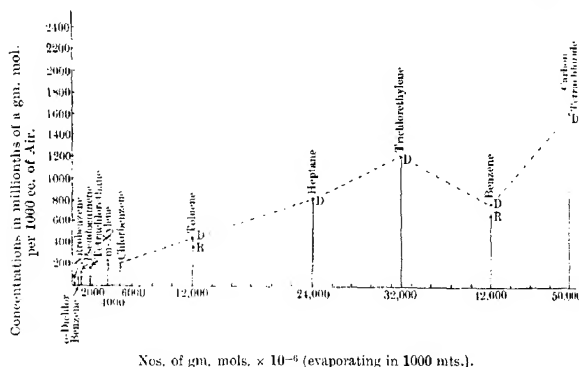
Substance.	Boiling point ° C.	Vapour pressure at 15° C. mm.	Approximate rate of evaporation gm. mol. $\times 10^{-6}$ 1000 mts.	Toxic concentration gm. mol. $\times 10^{-6}$ 1000 mts.
Carbon Disulphide	46	245	224,000	526 400
Dichlorethylene	54.5-56	—	137,000	3100
Chloroform	60.25 61.5	128	98,000	1040
Hexane (normal)	71.5	96	79,500	3000
Carbon Tetrachloride	76.8	72	50,200	1600
Benzene	80.3	58.9	42,000	775 650
Trichlorethylene	88-89	—	33,000	1200
Heptane	97	27	24,000	800
Toluene	111	17.2	12,000	120 350
Monochlorobenzene	132	6.75	4,830	200 170
m-Xylene	138.5	4.74	3,500	230 185
Tetrachlorethane	146-148	—	1,750	144 60
Pseudocumene	168	7.75	800	35 80
Mesitylene	163-164	23.53	740	—
p-Cymene	174.5-175.5	5.71	650	—
o-Dichlorobenzene	179	—	600	70-50
Nitrobenzene	205	—	200	24-16

3 cms. in diameter were filled to a depth of 2.5 cms. from the rim with the substances to be tested and allowed to stand for known lengths of time. The loss in weight due to evaporation was then determined by weighing and the results calculated to numbers of gram molecules evaporated in a period of 1000 minutes. The results are shown in Table XV and are plotted against the toxic values in Diagrams 17 and



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18, 17 indicating the values obtained for a variety of different compounds, and 18 those obtained for the aliphatic halogen derivatives and carbon disulphide. A decreasing rate of evaporation was frequently accompanied by an increased toxicity but benzene, chloroform and carbon disulphide were more toxic than corresponded with their high degree of volatility.



Nos. of gm. mols.  $\times 10^{-6}$  (evaporating in 1000 mts.).  
Diagram 17. Relationship between Rates of Evaporation and Toxicity.

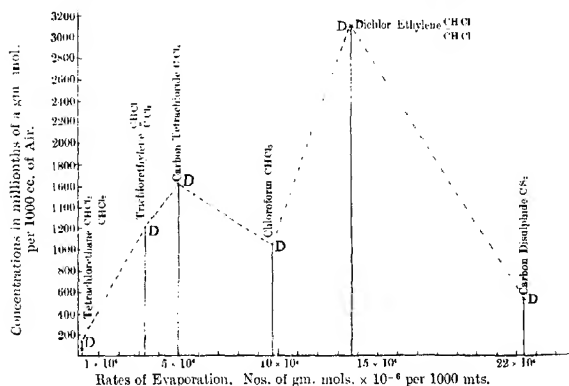


Diagram 18. Aliphatic Chlorine derivatives and Carbon Disulphide. Relationship between Toxicity and Rates of Evaporation.

## SUMMARY AND CONCLUSIONS.

1. The relationship between chemical constitution and toxicity to wireworms of organic compounds is found to be of a twofold nature.

2. The general effect of a group of compounds of the same type is directly determined by the chemical constitution of the type. The particular effects of individual members of the groups are limited by their physical properties such as volatility etc., which may be regarded as indirect consequences of their chemical constitution.

3. The aromatic hydrocarbons and halides are on the whole more toxic than the aliphatic hydrocarbons and halides. The groups that influence toxicity most when introduced singly into the benzene ring are in order of importance the methylenamido (most effective), dimethylenamido, hydroxy, nitro, amido, iodine, bromine, chlorine, methyl groups (least effective). But this order is modified in presence of another group: thus when there is a  $\text{CH}_3$  already present in the ring the order becomes chlorine (side chain), amido, hydroxy, chlorine (ring), methyl. Chlorine and hydroxy groups together give rise to highly poisonous substances considerably more effective than when present separately. The association of chlorine and nitro groups in chloropicrin gives rise to one of the most toxic substances tested. Methyl groups substituted in the amido group of aniline increase toxicity more than if substituted in the ring.

The list of substances tested and the order of effectiveness is given on page 208.

4. Compounds with irritating vapours have usually high toxic values, *e.g.* Allyl isothiocyanate, chloropicrin, benzyl chloride. The toxic values of these substances are not closely correlated with their vapour pressures or rates of evaporation.

5. There is a fairly close relationship between toxicities and the vapour pressures, rates of evaporation and volatilities of compounds of the same chemical type. In a series of similar compounds decreases in vapour pressure and in volatility are associated with an increased toxicity. A possible explanation is that condensation or adsorption takes place along the tracheal system when insects are submitted to the action of these vapours. On exposure once more to the open air these vapours diffuse out into the atmosphere, the rate at which they do so being a measure of the rapidity with which the insect recovers.

6. A limit is put upon toxicity by the decrease in vapour pressure, when it sinks too low to allow a toxic concentration in the vapour phase. Chemically inert compounds boiling above  $170^\circ \text{C.}$  are generally uncertain

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in their poisonous effect on wireworms after an exposure of 1000 minutes at 15° C. Nearly all organic compounds boiling above 215° C. are uncertain in their action, while those boiling above 245° C. are non-toxic. These limits depend on the resistance of the insect, the length of exposure and the temperature at which the experiment is carried out.

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ON THE RELATIVE GROWTH AND DEVELOPMENT  
OF VARIOUS BREEDS AND CROSSES OF CATTLE.

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## INTRODUCTION.

At the present time no exact records exist (except those given in *British Breeds of Live Stock* published by the Board of Agriculture and Fisheries<sup>1</sup> and by McConnell in his *Notebook of Agricultural Facts and Figures*<sup>2</sup>) which show the relative qualities of the various British breeds of cattle in respect of their ability to grow, fatten and increase in weight. Also there exists no estimate as to the actual average amount of food produced by the different breeds on slaughter and the average proportion of consumable meat and offal in the dead body.

An investigation was therefore begun to determine the relative merits of the different breeds in these respects, to analyse the conditions affecting growth in weight and proportional development in order to determine the most economical conditions and breeds for the production of meat.

With the development of the Live Stock Scheme and the provision of pure bred sires throughout the country, some definite standard is required to enable the more profitable breeds, grades and crosses to be determined. In Denmark a scheme described by Mørkeberg<sup>3</sup> exists to test the carcasses of pigs bred from subsidised sires. Some definite basis of comparison is also required to compare British with Continental breeds and which will enable breeders to see exactly where the different breeds excel. Hitherto there have been no reliable figures available which show the average weights and amounts of meat produced by the various breeds, most books being content with a statement that the breed is a small or a large one and with the quotation of a few isolated cases of weights that have been attained at different ages.

<sup>1</sup> *British Breeds of Live Stock*, Board of Agriculture and Fisheries, London, 1913.

<sup>2</sup> McConnell. *Notebook of Agricultural Facts and Figures*, London, 1904.

<sup>3</sup> Mørkeberg. *Tidsskr. Landøkonomi*, Nos. 5-6, 1916 (abs. in *Journal Dept. Agr. and Tech. Instr.*, Ireland, Vol. 17, No. 1, 1916).

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It may be said that a study of breeds, as such, is not possible owing to the large amount of variation which exists within a breed, and that cattle are plastic and by breeding can be modelled to the will of the breeder. The study of breeds, however, will show the results attained by the aggregate of the individuals of a breed which have been modelled to the standard laid down by the Breed Society; that is, it will show how far the standards of the various breed societies are conducive to the qualities investigated and how far their ideals are based on commercial qualities.

The results of the investigation, as described below, show that a definite comparison between different breeds can be made and that many of the factors which influence size and relative development can be unravelled. Although the investigation was necessarily very limited, sufficient has been done to show that a study of proportional development of animals, as yet practically untouched, is one which would well repay further investigation both from a practical and scientific point of view. It has also shown that Breed Societies could with advantage utilise the wide variation which at present exists in the proportions of the carcass weight to select animals which give a high proportion of flesh and less offal<sup>1</sup>.

In the same way it appears that there is scope for improvement as regards "weight for age" which must play an important part in the economic production of meat. There has perhaps been of late years a tendency to sacrifice "weight" for "quality" but data given below show that the smaller animals do not yield a larger proportion of "carcass" than the larger ones of the same age<sup>2</sup>. The importance of size—weight for age—has been impressed upon the farmer during the last few years by the system of "grading" fat cattle, but it is doubtful if the breeder of pedigree stock has been impressed to the same extent. Unless the latter realises the commercial importance of weight for age the farmer will not look on pedigree stock with much favour.

### MATERIAL.

As the collection of data concerning the growth and slaughterhouse tests for all the various breeds and crosses would involve much work

<sup>1</sup> Mackenzie and Marshall have found that a high proportion of carcass can be foretold by certain "outside" manifestations such as the condition of the hock, sitch bone, etc. (*Jour. Bd. Agric.* Vol. 25, Sept. 1918).

<sup>2</sup> No account here has been taken of the amounts of meat and bone in the "carcass," and it is possible that there is a greater percentage of bone in the "carcass" of the larger steers but no data on this point are available.

and expense, search was first of all made to see whether any such records existed already. It was considered that a study of existing records would enable definite points to be investigated in slaughterhouse tests and records of growth to be undertaken later and so render unnecessary much preliminary work with consequent waste of time and material.

With this object in view the catalogues of Agricultural Shows have been searched to find records of the weights attained by the various breeds of cattle. Unfortunately no complete record of cattle in a "breeding" as distinct from "fatted" condition has been found, the Royal Agricultural Society of England keeping no records of their shows.

The most complete and almost only data that have been published are those of the Smithfield Club of stock exhibited at the fat stock shows at Islington<sup>1</sup>. Copies of these records from 1893 to 1913 both inclusive have been obtained through the kindness of Mr E. J. Powell, the Secretary, and they form the basis of the present paper.

The animals exhibited at this show are probably maximum average specimens of their breed and are representative, thus forming better material for comparative purposes than would be obtained at any local show. Records taken from a local show tend to give undue prominence to the local breed.

The records are of fat animals and so the qualities of "growth" and "ability to fatten" are combined and it should be remembered when studying the results given below that the increase of weight is the result of these two factors. Although this fact renders the results of less value scientifically, as there must be uncertainty as to which factor is involved—growth or fattening—yet from a practical standpoint it is of the utmost value as these processes generally take place concurrently.

The weighing and recording of weights at the Smithfield Show have been carried out very accurately and are reliable. Mistakes however are possibly sometimes made, but the numbers of individuals of which records are obtained preclude possibility of the average being affected to any great extent. In addition to the record of weight, the age of each animal exhibited is stated, thus making the record doubly valuable.

Two series of competitions exist: (1) the live classes and (2) the carcass classes. In the first series a record is kept only of the age and gross weight attained by the animal. It is divided into groups for each

<sup>1</sup> If other Agricultural Shows would keep such records they would do much towards accumulating data which would be invaluable when treated statistically.

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breed (including one for cross-breeds) and these again subdivided into classes for different ages and sexes.

In the second series (carcase classes) in addition to a record of age and gross weight, details are given of the weight of the carcase, hide, head, heart, etc. after slaughter. This series is divided only into classes for the different ages and sexes. When compared with the number of exhibits in the live classes the entries for this series are very small and especially so in view of the fact that it is on the carcase result that selection in breeding should depend.

It should be remembered when discussing the results shown below that the animals here referred to have been specially treated and fed for "Show" purposes and that the conclusions drawn only apply to animals so treated and will not necessarily apply to ordinary farm stock produced on economic lines although the results here obtained will form a basis for the study of growth and fattening under ordinary farm conditions.

Long<sup>1</sup> has criticised the uneconomic production of meat as exhibited at Smithfield, especially with regard to the gains produced in the second to third year of life and the large differences in weight that exist between the animals shown in the live and carcase classes. Otis<sup>2</sup> who examined joints and did cooking tests from prize winning cattle at Chicago also came to the conclusion that "our improved breeds of beef cattle were getting to contain so large a percentage of fat that they were not so profitable from the butchers' standpoint as a plainer bred steer."

If the Smithfield Show aims at picking out the best type of animal for the butcher it would appear to be essential that all cattle exhibited there should be tested by slaughter and carcase competition in addition to their appearance while alive.

### METHODS.

The details given in the records quoted above have been treated statistically so as to give information on various points it was desired to investigate.

Weights throughout have been calculated in lbs. and decimals of a lb.; ages have been calculated in months and weeks.

In order to avoid confusion when discussing the results of the investigation below, the following account gives the methods by which the tables given in the text have been compiled:—

<sup>1</sup> Long. *Journ. Bd. of Agric. and Fisheries*, Vol. 21, April, 1914.

<sup>2</sup> Otis. *Kansas Sta. Bul.*, No. 118, 1903.

**Table I** has been compiled from the records of the Show direct. Weights have been converted from cwt. and qts. as given in the records to lbs. and decimals of a lb.

The groups "2 years old," and "2-3 years old," correspond with the divisions into classes at the Show. In the earlier years of the Show, classes were open for beasts of "3 years old and upwards," but these have not been included, except in the case of Highland cattle for which classes have been open to cattle of "under 3 years old" and "3-4 years old" so that these cattle are a year older than the other breeds.

The material has been grouped into three seven year periods: Period I from 1893 to 1899 both inclusive; Period II from 1900 to 1906 both inclusive; and Period III from 1907 to 1913 both inclusive.

The average for each of these periods has been calculated separately and the mean for the whole 21 years shown in the last column.

The number of individuals from which the average has been calculated is stated as a measure of the accuracy of the average. Averages calculated from less than 40 beasts are shown in italic type. The probable error of the mean has been calculated in a number of cases (see Table A). Part I of the table shows the averages for steers and Part II the averages for heifers.

Table A. *Live weight of cattle: probable error of the mean in lbs.*

Breed	Steers		Heifers	
	22 months	33 months	22 months	33 months
Shorthorn ... ..	5.62	7.65	22.37	8.32
Aberdeen Angus ... ..	6.73	8.78	28.55	7.04
Welsh ... ..	6.91	8.57	48.17	12.18
Aberdeen Angus ♂ × Shorthorn ♀ ... ..	12.33	23.57	11.92	18.00
Shorthorn ♂ × Aberdeen Angus ♀ ... ..	9.65	15.19	11.83	17.76

**Table II** has been calculated from the "Average" columns of Table I to eliminate the variation in age at which the breeds were exhibited. Corrections have been made by calculating the rate of growth per week in each breed (the weight at birth being taken as zero) and by adding or subtracting the number of weeks' growth required to complete 22 or 33 months. For example: Devon steers of "under 2 years" in Table I show an average age of 21 months, 3 weeks, and an average weight of 1203.9 lbs.; this is an average rate of growth of 14 lbs. per week; the addition of one week's growth to complete to 22 months brings the average of Devon steers to 1217.9 lbs. as shown in Table II.

As the rate of growth slackens with increasing age this method will not give quite accurate results, more especially for animals between 2 and 3 years old. The rate of growth was therefore calculated for animals of 33 months on the basis of the difference between the weight at "under 2 years old" and at "2-3 years old." This however made but little difference (about 5 lbs. on the average) in the results except in the case of the South Devons in which it amounted to 30 lbs. but which result would in any case be unreliable owing to the small numbers exhibited.



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The averages calculated from less than 40 individuals are shown in *italic type*. The weight at birth has not been allowed for as few records exist (apart from those given by Tomhave and Severson<sup>1</sup> for Shorthorns and Aberdeen Angus, by Hulse and Nevens<sup>2</sup> for Jerseys and Friesians, and by Stewart<sup>3</sup> for Shorthorns) of the average weights of the different breeds and sexes at birth. It was decided to neglect the weight at birth rather than to subtract a round figure of say 75 lbs. in each case, irrespective of breed or sex.

**Table III** has been compiled from the records of the carcass competitions direct. The weights have been converted from cwt.s., qrs. and stones, as given in the records of the Show, to lbs. and decimals of a lb. Ages are stated in months and weeks. The subdivision of breeds into "heifers" and "steers"; "under 2 years old" and "2-3 years old" corresponds with the division into classes at the Show.

The records have been divided into the same 7 year periods as shown in Table I, but, owing to the small numbers exhibited, only the averages for the whole 21 years are given here.

In each case is stated the number of beasts from which the average has been calculated and also the average age. Where the average has been calculated from under ten individuals it is shown in *italic type*.

The following is an explanation of the headings given to the various columns of this table which, with the exception of the first, are the parts into which the animal is divided after killing:

*Live weight.* This consists of the live weight of the animal as it is sent to the Show. During the period 1895 to 1902 the "live weight on arrival" and also the "fasted live weight" were shown separately. Only the "live weight on arrival" has been used in this paper and no figures for the "fasted live weight" have been included.

*Carcass weight.* Consists of the dressed carcass of the animal after it has been killed and the parts mentioned below have been removed.

*Suet fat.* Consists of the suet, caul (omentum), and reed (abomasum) fat.

*Gut fat.* Consists of gut fat and trimmings.

*Tongue.* Consists of the tongue and tail.

*Head.* Consists of the head and feet.

*Heart.* Consists of the heart, liver and lights (lungs and trachea).

*Tripe.* Consists of the tripe (rumen), fleck (manifold or 2nd stomach) and reed (abomasum) weighed together with their contents but minus the watery contents which drain away.

*Hide.* Consists of the hide alone.

*Blood.* Consists of the blood alone. The weight of this was only recorded from 1895 (when the carcass classes first started) until 1902. All the figures for blood therefore have been shown in brackets as they are not averages for the whole period.

*Intestines.* Consists of the intestines only, weighed after they were separated from the gut fat and after the bulk of their contents had been stroked out.

*Unaccounted for.* Consists of the weight unaccounted for when the sum of the weight of the foregoing parts (with the exception of blood) has been subtracted from

<sup>1</sup> Tomhave and Severson. *Pennsylvania Sta. Rpt.*, 1914-15.

<sup>2</sup> Hulse and Nevens. *Illinois Agric. Sta. Circular*, 1917.

<sup>3</sup> Stewart. *Am. Sci. Bul.*, Roy. Agric. College, Cirencester, Nos. 4-5, 1912-13.

the live weight. It will thus include the blood, loss of water by evaporation, water content of stomach, contents of intestines, loss of weight on cutting up as well as the loss in weight that occurs in the animal between the time that it reaches the Show and the time of slaughter. From the amounts given in the following tables it will be seen that blood accounts for about 2½ per cent. of the live weight. In meat killed for the Army<sup>1</sup> 1½ per cent. on all fresh meat is allowed for shrinkage in weight due to loss in evaporation and cutting up. The remainder of the loss—about ½ per cent.—is distributed among the other factors mentioned above.

The method of killing and weighing the animals exhibited at the Show has been the same during the whole of the period under review and has been superintended during this period by Mr J. Woodward to whom I am indebted for many of the details given above.

Table IV has been calculated from Table III in the same way that Table II has been calculated from Table I, by adding or subtracting the weekly rate of growth of the organ which would be required to complete to 22 or 33 months. In Table III, for example, the suet fat of Aberdeen Angus steers of 21 months 2 weeks old is shown as 14·6 lbs.; this works out at an average rate of increase of 0·15 lbs. per week; adding 2 weeks' growth to complete to 22 months brings the average of Aberdeen Angus steers to 14·9 lbs. as shown in Table IV. The same remarks concerning the method apply as stated under Table II above. All averages calculated from under ten individuals have been shown in italic type.

Table V has been compiled from Table IV by calculating the various organs and tissues as percentages of the live weight. Thus for the suet fat of Aberdeen Angus steers of 22 months

$$\frac{14.9 \text{ lbs. (suet fat)} \times 100}{1233.5 \text{ lbs. (live weight)}} = 1.21,$$

as shown in Table V.

At the end of this table an average has been compiled of all the animals exhibited; for example: the figure 64·27 per cent. for carcass weight of steers of 22 months has been arrived at by averaging the sum of 30 Aberdeen Angus at 64·33 = 1929·90; 3 Red Poll at 60·32 = 180·96, etc.

All the averages calculated from under ten individuals have been shown in italic type. The probable errors of the means have been calculated in a few cases and are shown in Table B.

Table B. *Carcass weight of cattle: probable error of mean in per cent. of live weight.*

Breed	Age months	Carcass	Suet fat	Gut fat	Tongue	Head	Heart	Tripe	Hide	Blood	In-testine	Un-accounted for
Galloway ...	33	·342	·047	·084	·009	·032	·045	·113	·073	·039	·029	·322
Aberdeen Angus ...	22	·267	·041	·081	·010	·042	·033	·170	·077	·044	·044	·186
Aberdeen Angus ...	33	·394	·047	·150	·015	·040	·060	·275	·110	·093	·040	·312
Welsh ...	33	·323	·034	·065	·008	·030	·027	·130	·086	·030	·042	·188

<sup>1</sup> Eastern Command Order, No. 2764 of 1917.

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**Table VI(a)** has been calculated by methods explained under Table II above from data given by Voitellier<sup>1</sup> collected at French Agricultural Shows. It has been shown in italic type, as the small numbers from which it has been compiled render the results unreliable.

**Table VI(b)** has been calculated by the methods explained under Table II above from data given by Lydtin<sup>2</sup>.

**Table VII** has been calculated from Table II by expressing the weight of the heifers as a percentage of the weight of the steers of the same age. Thus, for Herefords of 22 months,  $\frac{1282.3 \times 100}{1383.9} = 92.6$ .

The numbers from which the results have been calculated are given as a guide to their reliability. Where the number of individuals compared on either side is less than 20 the result is shown in italic type.

The probable error has been calculated from the formula

$$\frac{(Pe \text{ of } P)^2}{P^2} - \frac{(Pe \text{ of } M_2)^2}{M_2^2} + \frac{(Pe \text{ of } M_1)^2}{M_1^2},$$

where  $P$  = percentage of  $M_2/M_1$ . In the case of Aberdeen Angus of 33 months it is  $\pm 0.597$  per cent.

**Table VIII** has been calculated from Table II in the same way as the preceding table, by expressing the weight of each sex at 22 months as a percentage of the weight of the corresponding sex at 33 months. The numbers from which the results have been calculated are given as a guide to their reliability and, where the numbers of individuals compared on either side are less than 20, the result is shown in italic type.

The probable error has been calculated (from the same formula as in the last table) in the case of Aberdeen Angus steers and is  $\pm 0.536$  per cent.

**Table IX** has been compiled from the records of the Show direct in the same way as Table I. In column one the male parent of the cross has been given first in each case. Where the average has been calculated from less than 20 individuals the result is shown in italic type. The probable error is approximately 1.5 lbs. for the Aberdeen Angus-Shorthorn cross (see Table A).

**Table X** has been calculated from Table IX in the same way as Table II has been compiled from Table I (see above). The same remarks apply as in Table IX.

**Table XI** has been compiled from Table II by taking the mean between the averages for the two breeds concerned. Cases where the mean has been calculated on either side from less than 50 individuals have been shown in italic type.

**Table XII** has been calculated from Table X in the same way as Table VII (see above) has been compiled from Table II. The number of animals from which the results are calculated are given as a guide to their reliability. Where the figures are calculated on either side from less than 20 individuals the results are given in italic type.

**Table XIII** has been calculated from Table X in the same way as Table VIII has been calculated from Table II. Where the figures are calculated on either side from less than 20 individuals the results are given in italic type.

<sup>1</sup> Voitellier. *Ann. Sci. Agron.*, No. 1, 1914.

<sup>2</sup> Lydtin. *Arbeit. d. Deut. Landw. Gesell.*, Heft 90, 1904.

**Table XIV** has been compiled direct from the records of the Show in the same way as **Table III** (see above); the male parent of the cross is shown first in column one. Where the averages have been calculated from less than ten individuals the results are shown in *italic type*.

**Table XV** has been calculated from **Table XIV** in the same way that **Table IV** (see above) has been compiled from **Table III**. Where the averages are calculated from less than ten individuals the results are shown in *italic type*.

**Table XVI** has been compiled from **Table XV** in the same way that **Table V** (see above) has been compiled from **Table IV**. Results calculated from under ten individuals are shown in *italic type*.

**Table XVII** has been prepared direct from the records of the Show by first correcting the weight of each animal for age (see **Table II** above). The standard deviation has then been calculated on these corrected figures according to the formula  $\sqrt{\frac{\sum D^2 f}{n}}$ , and from this the coefficient of variability calculated according to the formula  $\frac{\sigma}{M}$ . The number of animals on which the calculation is based has been given in each case. Results based on under 30 individuals are shown in *italic type*. The average given at the end of the table has been compiled direct from the figures for each breed and the number of individuals concerned has not been taken into account.

**Table XVIII** has been calculated in the same way as the previous table, but the animals have been grouped according to the "period" in which they were exhibited; the "mean" used in the calculations being the mean of the "period" concerned and not the mean of the whole 21 years.

**Table XIX** has been prepared direct from the records of the carcass competitions of the Show by first correcting the weight of each animal for age (see **Table II** above), then converting the weights of the various organs to percentages of live weights (see **Table V** above); the standard deviation and coefficient of variability being calculated in the same way as in the two previous tables. The average at the end of the table has been prepared from the figures for each breed, the numbers of individuals concerned in each case not being taken into account.

**Table XX** has been compiled from the records of the carcass competitions of the Show by first correcting the weights of each animal for age (see **Table IV** above) and then converting the weights of the carcass and various organs to percentages of the live weight (see **Table V** above). The following groups have been treated in this way—Aberdeen Angus steers of 22 months old and 33 months old, Galloway steers of 33 months old and Welsh steers of 33 months old. Each of these groups has been arranged in order of proportion of some particular organ selected for correlation and then divided into as far as possible three equal classes: (1) highest, (2) average and (3) lowest. In the case of Aberdeen Angus steers of 22 months the ten animals with the highest proportion of tripe would be classed under (1); the ten with the lowest proportion of tripe under (3) and the remainder under (2). The weights of the various organs of animals falling into each class were then averaged separately. In this way each organ and tissue has been taken in turn and the individuals arranged, grouped and then averaged.

As the numbers for each breed exhibited were too small to give by themselves

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a reliable result, the whole have been combined by averaging the "highest" groups of each breed and by treating the "lowest" and "average" groups in the same way. The total number of individuals on which the calculation is based is shown in the second column of the table.

**Table XXI** has been compiled from Table I by correcting for age (see Table II) in each of the averages of the seven year periods.

**Table XXII.** The records on which the figures for 1840-42 are based are those of the Smithfield Show published in the *Farmer's Magazine* for those years. The 1893-1913 "live" class weights have been calculated by taking 64 % of the live weight as shown in Table II. The 1893-1913 "carcase" class weights for loose fat are the sum of the gut fat and suet fat with "trimmings."

**Table XXIII** has been prepared from Table III by correcting for age (see Table IV) in each of the seven year periods of the Aberdeen Angus, Galloway and Welsh breeds. The results have then been turned into percentages of the live weight and the whole averaged.

**Table XXIV** has been compiled direct from the records of the Show by first correcting for age (as described in Table II above) the weight of each steer of the following breeds—Welsh, Shorthorn and Aberdeen Angus. From these corrected figures the weights of the steers of the same age and breed were averaged separately for each year. The difference between this yearly average and the average for the breed as a whole (see Table II) is shown as a + or - quantity in this table. The seventh column gives the difference between the yearly average rainfall of England and Wales<sup>1</sup> and the average for the period 1893-1913. In the same way column eight gives the difference for the combined turnip and mangold crops and column nine for the combined permanent and temporary hay crops<sup>2</sup>.

### RESULTS.

The results of the investigation are considered below in sections under various headings. These—Breed, Sex, Age, Cross-breeding, Selection, Individual Variation, Correlation and Season—comprise the different factors which it was considered might have an effect on growth and development.

In general, the results obtained from the "live" classes for actual gross weight have been considered first and afterwards the proportional development as shown by the "carcase" classes has been discussed. A number of the conclusions arrived at below should be considered as tentative only owing to the small numbers on which the results are based. As however practically no data are available concerning these points it was considered that the publication of even tentative conclusions would be better than none at all.

<sup>1</sup> *British Rainfall*, Symonds and Wallis, London, 1893-1913.

<sup>2</sup> *Agricultural Returns for Great Britain*, Board of Agriculture and Fisheries, 1893-1913.



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### *Breed.*

Table I shows the averages of the "live" classes exactly as calculated from the records of the Show. A study of this table will show the popularity of the various breeds, according to the numbers exhibited, and the usual age at which the beasts are exhibited; but is not reliable as a comparison between breeds and sexes because of the variation in the average of the ages.

Table II has therefore been prepared to eliminate the differences due to age, and shows all breeds calculated for the purpose of comparison to the same ages, namely 22 and 33 months.

Table II. *Comparative weights of different breeds of cattle.*

Breed	Weights in lbs. and decimals of a lb.							
	22 months				33 months			
	No.	Steers	No.	Heifers	No.	Steers	No.	Heifers
South Devon ...	8	1512.0	—	—	31	1935.8	.	—
Shorthorn ...	187	1410.4	11	1316.9	161	1859.0	118	1688.8
Hereford ...	150	1383.9	20	1282.3	114	1845.3	58	1587.9
Sussex ...	189	1389.0	8	1312.5	165	1797.8	101	1636.7
Highland* ...	116	1435.3	24	1332.1	170	1785.1	95	1481.1
Aberdeen Angus...	193	1361.7	9	1288.8	155	1774.5	155	1599.5
Welsh ...	135	1371.1	8	1261.5	228	1691.8	96	1483.9
Red Poll ...	65	1276.2	3	1207.6	77	1630.4	57	1533.5
Galloway ...	98	1219.0	4	1270.5	120	1598.2	79	1349.3
Devon ...	166	1217.9	5	1242.4	186	1564.6	71	1409.9
Kerry ...	3	760.5	2	918.3	22	1089.1	13	988.0
Dexter ...	87	819.6	13	798.8	99	1029.5	65	919.2
Lincoln Red ...	2	1363.5	2	1524.7	..	..	—	—
Ayrshire ...	2	1012.4	—	—	—	—	—	—

\* One year older.

Table VI (a). *Weights of French breeds of cattle.*

Breed	In lbs.							
	22 months				33 months			
	Males		Females		Males		Females	
	No.	Weight	No.	Weight	No.	Weight	No.	Weight
Charollaise ...	1	1782	1	1205	1	2030	1	1230
Durhams ...	8	1641	3	1113	3	1912	2	1361
Hollandaise ...	—	—	1	1203	4	1885	1	1212
Normande ...	13	1758	4	1144	18	1866	4	1201
Parthenaise ...	4	1489	2	1161	4	1553	5	1291

Table VI (b). *Weights of German breeds of cattle.*

		In lbs.							
		22 months				33 months			
Breed		Bulls		Cows		Bulls		Cows	
		No.	Weight	No.	Weight	No.	Weight	No.	Weight
Large light coloured Mountain (Simmenthal) ... ..	...	5	1615	4	1357	8	1871	30	1379
Black and white German Lowland (Friesian, Jeverland, Wesermarsh) 28	...	1523	10	1016	18	1723	41	1278	
Pinzgau ... ..	...	2	1167	2	985	1	1718	2	1262
Pedigree Shorthorns ... ..	...	2	1318	1	1066	2	1591	3	1302
Grey-brown Mountain (Allgau) ... ..	...	3	1320	4	1046	6	1630	4	1192
Red and white Holstein ... ..	...	3	1357	—	—	8	1650	9	1153
Common Shorthorns ... ..	...	1	1146	—	—	3	1742	1	1197
Yellow Franken ... ..	...	4	1263	3	884	—	—	4	1247
Red East Friesian ... ..	...	6	1190	—	—	—	—	2	1155
Red Cattle of Central Germany ... ..	...	3	1019	7	757	2	1386	2	1014
Angeln ... ..	...	5	902	—	—	4	1126	4	972

Comparing the size of the various breeds it will be seen that in steers of 33 months old the South Devons are by far the heaviest; the Shorthorns come next, followed by the Hereford, Sussex, and Aberdeen Angus in the order named. There is then a fairly large gap of approximately 80 lbs. before coming to the Welsh breed and below this comes another group in the following order: Red Poll, Galloway and Devon. Highland cattle of approximately the same age come next, intermediate between the large and small breeds. The latter—the Kerry and the Dexter—are some 400–500 lbs. lighter than the Devons in weight.

Heifers of the same age show much the same variations as the foregoing. Hereford, Welsh and Galloway females however take a lower relative place in the table. This is probably due to the large sex differences which occur in these breeds.

When steers of 22 months old are compared, the breeds come in much the same order as at 33 months old. The Sussex, Welsh and Dexter breeds however take higher relative positions which bring them above the Hereford, Aberdeen Angus and Kerry breeds respectively.

Concerning heifers of 22 months old little can be said as the small numbers exhibited make comparisons unreliable. They show however in a smaller degree the same sex differences as have been referred to above for heifers of 33 months old.

It is interesting to compare the weights given in Table II with those



Table III. *The carcass weights of cattle shown at Smithfield, 1895-1913.*

Ages in months and weeks. Weights in lbs. and decimals of a lb.

Breed	Sex	Age	No.	Average age	Live weight	Carcass	Suet fat	Gut fat	Tongue	Head	Heart	Tripe	Hide	Blood	In- testine	Unac- counted for
South Devon	Steer	Under 2 yrs	5	22-2	1556-0	988-0	20-2	49-2	12-6	63-4	42-5	119-2	168-2	[32-0]	22-8	121-7
	Heifer	Under 2 yrs	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Shorthorn	Steer	Under 2 yrs	1	35-2	1815-0	1179-0	31-0	47-0	14-0	60-0	50-0	148-0	85-0	—	30-0	101-0
	...	Under 2 yrs	7	21-2	1310-6	878-1	16-1	33-9	10-4	50-0	35-0	108-1	89-1	[29-0]	18-3	110-6
Heifer	Under 2 yrs	4	31-2	1600-2	1046-2	27-7	47-7	13-0	58-0	41-0	100-0	90-2	[32-3]	20-2	147-1	—
	...	Under 2 yrs	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Hereford	Steer	Under 2 yrs	2	22-1	1282-0	817-5	17-0	32-0	11-5	48-0	30-0	96-5	97-0	[26-5]	16-0	116-5
	...	Under 2 yrs	1	32-2	1408-0	984-0	24-0	58-0	13-0	54-0	41-0	87-0	83-0	[28-0]	25-0	89-0
Stossex	Heifer	Under 2 yrs	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	...	Under 2 yrs	14	21-3	1385-0	903-4	17-8	30-6	11-0	55-2	34-6	102-3	101-4	[33-1]	17-9	104-8
Highland	Steer	Under 2 yrs	5	32-0	1699-8	1117-2	26-6	47-0	13-8	60-3	38-2	106-6	108-0	[33-5]	22-4	129-2
	...	Under 2 yrs	2	23-0	1144-5	733-0	21-5	27-5	10-0	43-0	28-5	104-5	75-5	—	16-0	85-0
Aberdeen Angus	Heifer	Under 2 yrs	1	35-1	1419-0	884-0	19-0	34-0	15-0	50-0	42-0	147-0	77-0	[37-0]	19-0	132-0
	...	Under 2 yrs	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Heifer	Under 2 yrs	7	31-3	1325-1	855-4	19-9	38-9	10-6	50-0	36-6	100-7	113-7	[32-0]	17-4	85-1	—
	...	Under 2 yrs	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Aberdeen Angus	Steer	Under 2 yrs	30	21-2	1205-3	775-5	14-6	27-8	9-8	49-5	32-9	96-8	78-6	[30-5]	16-1	103-7
	...	Under 2 yrs	16	32-0	1463-4	935-0	19-7	37-0	11-7	55-7	37-1	111-1	87-0	[30-1]	18-6	130-5
Heifer	Under 2 yrs	11	22-1	1109-6	717-5	17-5	23-1	9-8	41-7	30-0	102-6	67-2	[25-0]	15-8	84-3	—
	...	Under 2 yrs	15	32-1	1208-9	818-4	20-4	31-7	10-4	40-8	33-1	100-4	71-0	[28-3]	18-9	108-8



Table IV. *Comparative carcass weights of different breeds of cattle*

Weights in lbs. and decimals of a lb.															
Breed	Sex	Age months	No.	Live weight	Carcass	Shank fat	Gut fat	Tongue	Head	Heart	Tripe	Hide	Blood	In-testine	Unaccounted for
South Devon	Steer	22	5	1521.6	966.1	19.8	47.2	12.4	62.0	41.6	116.6	195.8	[31.3]	22.3	127.8
	Heifer	22	—	—	—	—	—	—	—	—	—	—	—	—	—
	Heifer	33	1	1687.2	1006.0	28.9	43.7	13.0	55.8	46.5	137.6	79.1	—	27.9	158.7
Shorthorn	Steer	22	7	1341.0	838.5	16.4	34.7	10.6	51.1	35.8	110.6	81.9	[29.7]	18.7	82.9
	Heifer	33	4	1676.4	1006.0	28.9	49.8	13.6	60.7	42.9	114.2	94.4	[33.8]	21.1	154.8
	Heifer	22	—	—	—	—	—	—	—	—	—	—	—	—	—
Hereford	Steer	22	2	1267.6	808.5	16.8	31.7	11.4	47.5	29.5	95.4	95.9	[29.2]	15.8	115.1
	Heifer	33	1	1490.6	966.1	24.4	58.9	13.2	51.8	41.6	88.3	94.4	[28.4]	25.4	99.5
	Heifer	22	—	—	—	—	—	—	—	—	—	—	—	—	—
Sussex	Steer	22	14	1400.9	913.8	18.0	37.0	11.1	55.8	35.0	103.5	102.6	[33.5]	18.1	106.0
	Heifer	33	5	1721.9	1152.0	27.4	48.4	14.2	62.6	39.4	109.9	111.4	[34.6]	23.0	133.6
	Heifer	22	2	1094.8	701.2	20.6	26.3	9.6	41.2	27.3	100.0	72.3	—	15.3	81.0
Highland	Steer	22	—	—	—	—	—	—	—	—	—	—	—	—	—
	Heifer	33	7	1377.1	888.9	20.6	40.4	11.0	51.9	37.9	104.7	118.0	[33.2]	18.0	85.7
	Heifer	22	—	—	—	—	—	—	—	—	—	—	—	—	—
Aberdeen Angus	Steer	22	30	1233.5	783.5	14.9	28.4	10.0	50.6	33.6	99.0	80.4	[31.2]	16.5	105.6
	Heifer	33	16	1500.0	984.6	20.3	38.2	12.0	57.4	38.3	114.5	89.7	[31.0]	19.1	134.9
	Heifer	22	11	1097.0	700.4	17.3	22.8	9.7	41.2	29.7	101.4	66.5	[22.8]	15.6	83.4
Heifer	33	15	1208.3	837.4	20.8	32.4	10.7	47.9	32.8	111.9	72.6	[28.9]	19.3	111.5	

Welsh	...	Steer	22	17	1238.7	735.2	17.3	36.3	10.1	51.5	34.3	92.0	100.5	[35.1]	17.5	99.0
		Heifer	33	31	1436.0	900.7	24.8	41.3	11.0	50.1	38.9	111.9	104.5	[37.1]	18.2	122.8
			22	1	1238.0	705.9	15.4	36.0	12.7	47.6	35.2	114.1	77.4	—	19.4	112.6
			33	8	1261.0	801.0	23.6	36.5	10.5	46.0	34.6	104.3	79.5	—	20.2	104.3
Red Poll	...	Steer	22	3	1237.6	745.5	14.3	46.6	10.5	52.6	42.5	114.2	32.0	[29.3]	22.2	112.2
		Heifer	33	3	1400.6	910.8	23.4	45.0	10.5	55.3	34.1	105.2	83.9	[35.5]	23.4	105.9
			22	2	890.6	576.6	16.4	25.0	7.3	34.1	26.0	64.2	52.7	—	12.8	76.5
			33	—	—	—	—	—	—	—	—	—	—	—	—	—
Galloway	...	Steer	22	13	1140.0	729.5	16.8	29.7	10.1	48.4	31.1	90.9	81.4	[25.2]	15.1	88.0
		Heifer	33	28	1452.5	934.1	23.1	44.2	11.8	57.4	36.3	111.0	94.9	[35.0]	19.1	120.6
			22	3	1104.5	711.5	16.6	28.8	10.9	42.8	28.7	85.8	75.3	[26.8]	75.0	86.2
			33	4	1231.3	807.3	23.2	33.6	11.3	46.5	32.0	93.5	76.1	—	19.1	89.7
Devon	...	Steer	22	3	1199.5	712.3	13.9	27.9	10.9	47.0	30.6	97.9	82.0	[33.8]	17.1	90.9
		Heifer	33	3	1444.0	937.8	22.5	45.6	11.3	53.7	37.0	103.4	91.0	[30.9]	19.0	123.7
			22	—	—	—	—	—	—	—	—	—	—	—	—	—
			33	1	1352.6	867.0	20.8	46.8	12.1	53.2	36.1	108.4	93.6	[31.6]	33.2	76.4
Kerry	...	Steer	22	1	1614.0	838.0	7.6	18.2	6.7	32.5	18.2	54.6	48.8	[21.1]	8.6	70.7
		Heifer	33	2	1347.1	835.9	20.4	50.2	12.4	53.2	34.7	102.7	93.6	[25.6]	19.9	124.1
			22	—	—	—	—	—	—	—	—	—	—	—	—	—
			33	2	1153.1	714.5	28.9	43.1	9.5	41.6	32.7	90.7	71.7	[27.4]	16.8	103.6
Dexter	...	Steer	22	—	—	—	—	—	—	—	—	—	—	—	—	—
		Heifer	33	2	1114.7	702.5	25.7	41.8	9.1	43.3	26.2	80.1	71.0	[27.2]	24.7	120.3
			22	1	856.6	534.8	17.6	28.4	6.8	34.3	24.5	63.6	63.6	—	17.6	65.4
			33	3	994.4	635.7	20.9	35.9	9.9	38.7	27.6	61.9	63.6	[19.0]	19.0	82.1
Ayrshire	...	Steer	22	—	—	—	—	—	—	—	—	—	—	—	—	—
		Heifer	33	1	1325.4	817.0	24.6	36.9	11.3	53.3	35.9	94.3	87.1	[28.7]	29.5	144.5
			22	—	—	—	—	—	—	—	—	—	—	—	—	—
			33	—	—	—	—	—	—	—	—	—	—	—	—	—

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compiled by Watson and Harrison<sup>1</sup> for cattle exhibited at the International Live Stock Exposition, Chicago in 1907-8 and 9. These authors show the average for two-year-old steers as follows: Herefords 1639 lbs., Shorthorns 1617 lbs., Aberdeen Angus 1571 lbs. and Galloway 1437 lbs. It will be seen that in America the Hereford is larger than the Shorthorn, and that even when allowance has been made for the fact that they are two months older, the American breeds are each some 200 lbs. heavier than the British type.

It is also interesting to compare Table II with the weights attained by Continental breeds as shown in Table VI (a). This table has been compiled from data collected by Voitellier<sup>2</sup> who weighed and measured many of the prize cattle exhibited at the French Agricultural Shows in 1912. The sexual differences here are greater than with British breeds because the weights are of uncastrated animals. It will be seen that the males are much heavier but the females weigh less than those of the British breeds. Unfortunately no records are available for cattle shown under the same conditions as at Smithfield.

Pusch<sup>3</sup> gives the average weights of bulls and cows of the various breeds of German cattle but states only round figures and does not give the exact age or weights on which his figures are based. Lydtin<sup>4</sup> however collected data of the weights of German cattle, not in "show" condition, and from his data, Table VI (b) has been compiled. The same remarks apply as in the case of the French breeds. It would be interesting to compare the weights of these "show" cattle as given in Table II above with the weights attained by the ordinary run of cattle kept for the economic production of meat. Meek<sup>5</sup> studied the growth rate of ordinary Shorthorn cattle but his paper I have been unable to obtain. Table III shows the average of the "carcase" classes exactly as calculated from the records of the Show; it does not form a reliable basis for a comparison between breeds however owing to the variation in the average of the ages at which they were shown. Table IV has therefore been prepared to eliminate the differences due to age and this table shows all breeds calculated for the purposes of comparison to the ages of 22 and 33 months.

<sup>1</sup> Watson and Harrison. *Breeders Gaz.*, No. 18, 1910 (quoted from *Exp. Sta. Record*, 23). As these authors state that the American are not so heavy as the English types of the same breed it is difficult to reconcile their statements unless the ages have been misquoted.

<sup>2</sup> Voitellier. *Bul. Mens. d. l'Off. Renseignements Agricoles*, Year 12, No. 1, Jan. 1913.

<sup>3</sup> Pusch. *Allgemeine Tierzucht*, Stuttgart, 1911.

<sup>4</sup> Lydtin. *Arb. Deut. Landw. Ges.*, Heft 90, 1904.

<sup>5</sup> Meek. *Veterinarian*, Vol. 74, 1901.

If the average "live weight" as calculated in this table is compared with that shown in Table II for the corresponding age, breed, and sex, it will be seen that the former is very much less in almost every case.

While Sussex steers of 22 months are actually a few pounds heavier in the "carcase" than in the "live" classes, Aberdeen Angus steers of the same age are some 130 lbs. and at 33 months some 260 lbs. lighter than in the "carcase" classes. Welsh steers of 22 and 33 months are 130 lbs. and 190 lbs. lighter respectively, and Galloway steers are 80 lbs. and 140 lbs. lighter respectively in the "carcase" than in the "live" classes.

It would thus seem that two different types of animals are shown, one for the "live" and another for the "carcase" classes. Possibly the amount of fat required to please the judges in the "live" classes is not conducive to a good carcase, or possibly the best beasts are not entered for the "carcase" competition. At any rate there seems to be a difference between these two competitions which should not exist if they are both designed to demonstrate the best quality and most economical beef animal.

This difference in weight between the two competitions has been already brought to notice by Long<sup>1</sup> who attributes the differences to surplus fat in the "live" classes. Powell<sup>2</sup>, however, in defence of the system says that "because animals are brought to the show in such condition, there is no reason why they should never be killed until in that condition; and such a breed that will get so excessively fat, will certainly become moderately so, sooner than another breed that can never be overfed to such a pitch with any degree of attention that can be bestowed upon it." If all cattle exhibited at the Show were subjected to the carcase test no doubt excessive fat would be eliminated.

In order to obtain the proportions of the various organs and tissues the actual weights of the carcase and different organs have been calculated in percentages of the live weight and are shown in Table V. The various breeds differ considerably in the proportion of carcase produced but in many cases the number of animals from which the results are calculated is too small to be reliable as a large amount of individual variation exists (see Variation below). Only those breeds are referred to here which have been exhibited in sufficient numbers to justify tentative conclusions being drawn.

<sup>1</sup> Long, *Journ. Bd. of Agric. and Fisheries*, Vol. 21, April, 1914.

<sup>2</sup> Powell, *History of the Smithfield Club*, London, 1902.



Welsh...	...	...	22	17	64.03	1.39	2.03	0.81	4.16	2.77	7.42	7.33	12.881	1.41	7.77
	Steer		33	31	64.09	1.05	3.17	0.73	3.94	2.90	7.44	6.37	12.061	1.21	7.82
	Heifer		22	1	62.45	1.58	2.44	1.03	3.39	2.76	9.29	6.30	—	1.58	8.45
			33	8	63.52	1.87	2.89	0.83	3.65	2.74	8.31	6.30	—	1.57	8.36
Red Poll	...	...	22	3	60.32	1.15	3.28	0.65	4.25	3.43	9.23	6.62	[2.37]	1.79	9.08
	Steer		33	3	65.03	1.67	3.21	0.76	3.95	2.43	7.51	5.99	[2.75]	1.67	7.78
	Heifer		22	2	64.74	1.34	2.81	0.82	3.82	2.92	7.21	5.92	—	1.44	8.48
			33	—	—	—	—	—	—	—	—	—	—	—	—
Galloway	...	...	22	13	64.00	1.39	2.61	0.88	4.24	2.73	7.98	7.14	[2.21]	1.32	7.71
	Steer		33	28	64.31	1.59	3.04	0.81	3.95	2.49	7.64	6.52	[2.40]	1.32	8.33
	Heifer		22	3	64.42	1.67	2.61	0.98	3.87	2.60	7.77	6.82	[2.42]	1.44	7.82
			33	4	65.66	1.88	2.73	0.92	3.69	2.60	7.59	6.18	—	1.55	7.30
Devon...	...	...	22	3	64.39	1.16	2.32	0.99	3.92	2.55	8.15	6.83	[2.82]	1.42	8.86
	Steer		33	3	64.94	1.55	3.16	0.78	3.72	2.56	7.16	6.30	[2.14]	1.32	8.50
	Heifer		22	—	—	—	—	—	—	—	—	—	—	—	—
			33	1	64.10	1.54	3.46	0.89	3.93	2.66	8.01	6.92	[2.34]	2.82	5.67
Kerry	...	...	22	1	60.00	1.14	2.74	1.01	4.91	2.74	8.22	7.35	[3.17]	1.30	10.59
	Steer		33	2	62.05	1.51	3.72	0.92	3.95	2.58	7.62	6.95	[1.90]	1.48	8.22
	Heifer		22	—	—	—	—	—	—	—	—	—	—	—	—
			33	2	61.96	2.51	3.74	0.82	3.61	2.83	7.86	6.22	[2.38]	1.46	8.99
Dexter	...	...	22	—	—	—	—	—	—	—	—	—	—	—	—
	Steer		33	2	61.37	2.24	3.65	0.79	3.78	2.29	7.00	6.20	[2.37]	2.17	10.61
	Heifer		22	1	62.43	2.05	3.32	0.79	4.00	2.86	7.42	7.42	—	2.65	7.66
			33	3	63.93	2.01	3.61	0.99	3.89	2.77	6.22	6.40	[1.91]	1.91	8.27
Avshire	...	...	22	—	—	—	—	—	—	—	—	—	—	—	—
	Steer		33	1	61.64	1.85	2.78	0.85	4.02	2.71	7.11	6.57	[2.16]	1.54	10.93
	Heifer		22	—	—	—	—	—	—	—	—	—	—	—	—
			33	—	—	—	—	—	—	—	—	—	—	—	—
Average of all breeds			22	95	64.27	1.28	2.61	0.82	4.09	2.70	7.85	6.94	[2.49]	1.37	8.07
	Steer		33	103	64.61	1.48	3.02	0.79	3.93	2.55	7.43	6.66	[2.82]	1.31	8.22
	Heifer		22	20	64.35	1.67	2.34	0.89	3.78	2.70	8.72	6.29	[2.15]	1.50	7.76
			33	36	64.22	1.76	2.79	0.85	3.71	2.69	8.15	5.94	[2.21]	1.57	8.32



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The following Table C gives the order of the breeds according to the proportions of their parts, calculated on the average weights of steers of 22 and 33 months. The breeds at both ages have also been considered separately in this way and much the same order is maintained whichever age is selected.

Table C. *Order of breeds as regards proportions of parts.*

Highest per cent. shown first.						
Order	<i>Carcass</i>	<i>Suet fat</i>	<i>Gut fat</i>	<i>Tongue</i>	<i>Head</i>	<i>Heart</i>
1	Shorthorn	Welsh	Welsh	Galloway	Galloway	Welsh
2	Sussex	Galloway	Galloway	A. Angus	Welsh	A. Angus
3	A. Angus	Shorthorn	Shorthorn	Sussex	A. Angus	Galloway
4	Galloway	Sussex	Sussex	Welsh	Sussex	Shorthorn
5	Welsh	A. Angus	A. Angus	Shorthorn	Shorthorn	Sussex
Order	<i>Tripe</i>	<i>Hide</i>	<i>Blood</i>	<i>Intestine</i>	<i>Unaccounted for</i>	
1	A. Angus	Welsh	Welsh	Shorthorn	A. Angus	
2	Galloway	Sussex	Galloway	Galloway	Galloway	
3	Shorthorn	Galloway	A. Angus	Sussex	Welsh	
4	Welsh	A. Angus	Sussex	Welsh	Shorthorn	
5	Sussex	Shorthorn	Shorthorn	A. Angus	Sussex	

It will be seen that certain parts of the body are more or less correlated, for example, suet fat and gut fat in which the breeds stand in the same relative order, and also heart and blood in which approximately the same relative order is maintained. As regards intestine the differences between breeds are very small.

Kennedy<sup>1</sup> who compared beef with dairy breeds found that the dairy type had the higher proportion of offal and lower percentage of dressed weight as well as a higher percentage of fat in the internal organs.

The underlying causes for these breed differences are undoubtedly the standards laid down by the Breed Societies and the amount of attention which has been paid to the slaughter test in the selection of breeding animals as well as the conditions under which the animals are reared.

### *Sex.*

Some of the variations due to sex have been referred to above and are so great that it is remarkable that they have not received more attention. The sex differences are shown in Table II, and from this Table VII has been prepared to show the relative weights of the sexes of the different breeds at the ages of 22 and 33 months. In each case the weight of the heifer is shown as a percentage of the weight of the

<sup>1</sup> Kennedy et al. *Iowa Sta. Bul.*, No. 81, 1905.

steer at the same age. In many cases the figures given are unreliable owing to the small number of individuals from which they were calculated and these are shown in *italic type*.

Table VII. *Cattle—relative weights of the sexes.*

Breed	22 months				33 months			
	Steers		Heifers		Steers		Heifers	
	No.	Weight	No.	Weight	No.	Weight	No.	Weight
Red Poll ...	65	100	3	94.6	77	100	57	94.1
Sussex ...	189	100	8	94.5	165	100	101	91.0
Shorthorn ...	187	100	11	93.4	161	100	118	90.8
Kerry ...	3	100	2	120.7	22	100	13	90.7
Aberdeen Angus ...	193	100	9	94.6	135	100	155	90.1
Devon ...	116	100	5	102.9	186	100	71	90.1
Dexter ...	37	100	13	97.4	99	100	65	89.2
Welsh ...	135	100	8	92.0	228	100	96	87.7
Hereford ...	150	100	29	92.6	114	100	58	85.8
Galloway ...	98	100	1	104.8	120	100	79	84.4
Highland* ...	116	100	21	92.8	170	100	95	82.9
Lincoln Red ...	2	100	2	111.8	—	—	—	—

\* One year older.

When considering this table it should be remembered that a castrated male is being compared with a female; further investigation is required before it can be ascertained how much of this difference is due to sex and how much to the effect of castration.

The effect of castration on growth and weight for age is yet far from settled. Knight<sup>1</sup> found that neither early nor late castration materially affected the weight of Deccan bullocks although it led to greater proportional development in the hind quarters of early as compared with late castrated animals.

Recently, since cattle have been sold by weight on the system of "grading," several farmers have not castrated their calves believing that they would thereby increase the weight of the animal when sold fat.

Tandler and Keller<sup>2</sup> found that the removal of the sex glands in young cattle affected their conformation considerably.

Schuppli<sup>3</sup> gives for two breeds of cattle the following average weights of bulls, steers and heifers at  $2\frac{1}{2}$  years old:—

Breed	Bulls lbs.	Steers lbs.	Heifers lbs.
Murboden ...	1485	1082	1010
Pinzgau ...	1507	1181	1019

<sup>1</sup> Knight. *Dept. Agric., Bombay*, Bul. 61, 1914.

<sup>2</sup> Tandler and Keller. *Arch. für Entwicklungs.*, Bd. 31, 1910.

<sup>3</sup> Schuppli. *Jahresb. Steiermärk. Landw. Landes-Lehranst.*, 1911 (abs. in *Bul. Inter. Inst. Rome*, No. 8, 1912).

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If the weight of the steers of each breed is taken as 100 and the weight of the bulls and heifers calculated as a percentage of it the following result is obtained:—

Breed	Bulls	Steers	Heifers
Murboden ...	137.2	100.0	93.3
Pinzgau ...	127.6	100.0	86.3

It will thus be seen that castration modifies the sexual difference considerably as regards weight and that steers are much lighter than bulls of the same age.

Halnan and Marshall<sup>1</sup> found with guinea-pigs that removal of the testes does not affect the growth of the animals before sexual maturity. In these animals however there is very little difference in weight between the sexes at maturity.

Hatai<sup>2</sup> who experimented with rats found that where, after removal of the sex glands, there is compensating growth of the pituitary, there is no overgrowth of the body or obesity but that these responses appear when enlargement of the hypophysis does not occur.

Mackenzie and Marshall<sup>3</sup> also found with pigs that spaying causes increase in weight after the animals have reached a certain age and Hartmann<sup>4</sup> found with pigs that the effect of spaying was not seen in increased weight until the eleventh month of life.

The evidence available seems to indicate that castration in the male causes decrease in body weight, while spaying in the females leads to increased weight.

From Table VII it will be seen that the various breeds at 33 months old differ by about 10% in the relative difference in weight between the sexes. Red Polls show the least difference between the sexes (heifers 94.1 % of steer weights) followed by Sussex, Shorthorn, Aberdeen Angus, Devons and Dexter in the order mentioned. Increased sex differences are shown by the Welsh, Hereford and Galloway amounting to 87.7, 85.8 and 84.4 % respectively. At 22 months old these sexual differences are not so marked. On the whole it will be seen that there are great differences in weight between steers and heifers at 22 months old and that these differences increase with age. With Herefords the difference at 22 months is 7.4 % whereas at 33 months the difference is 14.2 %.

<sup>1</sup> Halnan and Marshall. *Proc. Roy. Soc. B.* Vol. **88**, 1914.

<sup>2</sup> Hatai. *Journ. Exp. Zool.*, No. 1, 1915.

<sup>3</sup> Mackenzie and Marshall. *Journ. Roy. Agri. Soc.*, Vol. **76**, 1915.

<sup>4</sup> Hartmann. *Mitt. Ver. Deut. Schweinezeit.*, Nos. 22-23, 1909 (quoted from *Exp. Sta. Record*, **23**).

It would appear also that the greater the sexual difference at 22 months old the greater is the increase in the difference at 33 months old. Thus with Herefords, as quoted above, with a difference of 7.4 % at 22 months the increased difference at 33 months is approximately 7 %, whereas with Aberdeen Angus where the difference is only 5.4 % at 22 months the increased difference at 33 months is only 4.5 %.

Thus difference in body weight between the sexes seems to vary in the same way as other secondary sexual characters (growth of horns, etc.) and to increase with age.

It is difficult to account for these variations in sexual differences between breeds, but Pusch<sup>1</sup> states that the sexual differences are greatest in cattle kept for labour and least in Lowland cattle of the dairy breeds.

Table VIII which has been prepared to show the relative weights at different ages shows very clearly that the heifer as compared with the steer puts on a relatively greater proportion of its eventual weight during the first 22 months of its life. About 77 % of a steer's weight at 33 months is put on during the first 22 months of its life whereas a heifer during this period would put on about 81 %.

The growth period of castrated male as compared with female cattle is more prolonged, the former continuing to put on weight after the latter have slackened off. Whether this is due to sex or only to castration effect it is difficult on the present data to decide; it is a point however which is worth further investigation.

This result confirms the finding of Watson and Harrison<sup>2</sup> who investigated the records of the International Live Stock Exposition at Chicago. They found that females approach their final weight somewhat faster than males, but the greater weight of the male is attained by greater daily gains being longer sustained than in the case of the female.

Sex differences are shown not only in the gross weight of the animal but also in the relative development of its parts. For example it is well-known that both the size and shape of the horns differs considerably in bulls, cows and steers. Tandler and Keller<sup>3</sup> found that spaying young cattle altered their conformation considerably. The average proportions of the different sexes for all the individuals of the pure breeds exhibited are shown at the end of Table V and those of cross-bred animals at the end of Table XVI.

These averages are not altogether reliable guides as to the differences

<sup>1</sup> Pusch. *Allgemeine Tierzucht*, Stuttgart, 1930, 1911.

<sup>2</sup> Watson and Harrison. *Breeders Gaz.*, No. 18, 1910 (quoted from *Exp. Sta. Record*, 23).

<sup>3</sup> Tandler and Keller. *Zentbl. Physiol.*, Bd. 23, No. 26, 1909.

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between the sexes, for the tables are compiled from varying numbers of the different breeds and so include variations due to the proportions in which the different breeds were exhibited. If however these averages are compared with those of the breeds and crosses shown in roman type in Tables V and XVI it will be seen that the following tentative conclusions may be arrived at:—

*Carcase.* Taken as a whole, steers show a slightly higher percentage of carcass weight than heifers.

*Suet fat.* The results confirm the generally well-known fact that heifers have more internal fat than steers. Heifers of pure breeds at 22 months have approximately 1.7 % of suet fat as compared with 1.3 % for steers of the same age and at 33 months old have 1.8 % as compared with 1.5 % for steers. This difference however is not so obvious in the case of cross-bred animals. Cross-bred heifers at 22 months have 1.6 % suet fat as compared with 1.5 % for steers and at 33 months old 1.8 % as compared with 1.6 % for steers. This helps to confirm the conclusions arrived at below (see Cross-breeding) that the effect of crossing is to obliterate sex differences (as is shown in extreme cases by mules).

*Gut fat.* With gut fat, conditions are reversed, and the steer carries a slightly larger proportion than the heifer.

*Tongue and tail.* The tongues (including tail) of heifers are larger in proportion by about .1 % than those of steers. Possibly this is brought about by the size of the tongue (and tail) tending to remain constant while the remainder of the body of the steer grows larger. Or possibly as with suet fat the tongue acts as a storehouse for fat more readily in the female.

*Head.* The head is proportionately heavier in steers than in heifers and is probably correlated with the larger bone growth in males. This difference unlike that of most sexual characters decreases with age, being approximately .4 % at 22 months and .1 % at 33 months.

*Heart.* No difference exists between the proportions of the hearts of the two sexes at 22 months, but at 33 months that of the heifer is slightly larger.

*Tripe.* At 22 months old heifers have about .9 % more tripe in proportion than steers and slightly more than this at 33 months old. In cross-bred animals the difference between the sexes is not so great.

*Hide.* Both at 22 and 33 months old the hides of steers are about .5 % larger in proportion than those of heifers.

*Blood.* Although the figures for blood are very meagre it would appear that at 22 months old steers have a greater proportion than

heifers while at 33 months the proportion in both sexes is about the same.

*Intestine.* Heifers have larger intestines in proportion than steers and this difference tends to increase slightly with age.

*"Unaccounted for."* The amount of the animal unaccounted for at 22 months is slightly greater in proportion in heifers than in steers, but at 33 months old both are practically the same.

The above sexual differences in the proportions of the body may be summarised as follows. Steers have a larger proportion of gut fat, head, hide, carcase (and blood at 22 months only), while heifers have a larger proportion of suet fat, tongue, tripe, intestine (heart at 33 months only), (and "unaccounted for" at 22 months only).

#### *Age.*

Table VIII which has been compiled from Table II shows the relative weights of cattle at different ages. In this table the weight at 22 months has been shown as a percentage of the weight at 33 months. These figures show the relative values of the various breeds as regards early maturity (growth in weight), in addition however it will include the quality of ability to lay on fat and so weight at the older ages.

Table VIII. *Cattle—relative weights at different ages.*

Breed	Steers				Heifers			
	22 months		33 months		22 months		33 months	
	No.	Weight	No.	Weight	No.	Weight	No.	Weight
Welsh ... ..	135	81.0	228	100	8	85.0	96	100
Highland* ... ..	116	80.3	170	100	24	89.9	95	100
Dexter ... ..	87	79.6	99	100	13	86.8	65	100
Red Poll ... ..	65	78.4	77	100	3	78.7	57	100
Devon ... ..	116	77.8	186	100	5	83.1	71	100
Sussex ... ..	189	77.2	165	100	8	80.2	101	100
Aberdeen Angus ... ..	193	76.7	155	100	9	80.6	155	100
Galloway ... ..	98	76.2	120	100	4	94.1	79	100
South Devon ... ..	8	76.0	31	100	—	—	—	—
Shorthorn ... ..	187	75.8	161	100	11	78.0	118	100
Hereford ... ..	150	75.0	114	100	20	80.7	58	100
Kerry ... ..	3	70.1	22	100	2	93.0	13	100

\* One year older.

In steers of 22 months breeds stand in the following relative order as regards early maturity: Welsh (81.0 %), Dexter, Red Poll, Devon, Sussex, Aberdeen Angus, Galloway, South Devon, Shorthorn, and Hereford (75.0 %).

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This order does not correspond to that which would be given by a breeder if asked for a list of breeds in order of early maturity. It may be that the popular ideas are incorrect or that they are based on qualities other than weight.

Heifers, although the data are rather unreliable owing to the small numbers exhibited, show approximately the same breed variations with the exception of slight differences probably due to sex; for example, Hereford heifers grow relatively less in the third year than Aberdeen Angus heifers (see Sex above) and so are more early maturing than the steers and take a higher place in the table.

The investigations of Watson and Harrison<sup>1</sup> confirm this. They state that "the Angus approaches full weight more quickly than the Shorthorn; this is true of both sexes. The Hereford figures correspond to the Shorthorn in the male and the Angus in the female, i.e. the early maturity of the female Hereford is accentuated."

Probably the above-mentioned order of early maturity is influenced by the ability of the breed to put on fat in the later stages of life; for example, the Sussex is usually thought to be a slow maturing breed but as old Sussex cattle probably put on little fat (and so weight) it has caused the breed to take a higher place in the table than it would otherwise have done.

As to the cause of early maturity little is known, but Müller<sup>2</sup> states that it is due not exclusively to nutrition but is also influenced by the balance of the glands of internal secretion. That nutrition has a very profound influence on it is shown by the experiments of Henseler<sup>3</sup> on pigs. Continental breeds on the whole show slightly greater early maturity ratios than those of British breeds—for bulls—Simmenthal 86.2 %, Black and White Lowland 88.4 % and Allgäu 80.9 %. As with all other animals, there is a slowing down of the rate of growth with age but the rate of slowing down depends on the breed.

The average rate of growth of Shorthorn steers (if 80 lbs. is allowed for the weight of the calf at birth) during the first 22 months of life is approximately 15 lbs. per week, but between the ages of 22 and 33 months, it falls to just over 10 lbs. per week and probably most of this increase is due to fattening rather than true growth. Long<sup>4</sup> has pointed this fact out very clearly.

<sup>1</sup> Watson and Harrison. *Breeders Gaz.*, No. 18, 1910.

<sup>2</sup> Müller. *Deutsche Landwirtschaftliche Tierzucht*, Year 18, No. 1, 1914.

<sup>3</sup> Henseler. *Kühn-Archiv, Unt. Halle*, Bd. 5, 1914.

<sup>4</sup> Long. *Journ. Bd. of Agric. and Fisheries*, Vol. 21, April, 1914.

The following figures taken from various experiments show the extent to which the rate of growth in weight varies with age:

Authority	Average daily gain in weight—lbs.			
	Calves	Yearlings	2-year-olds	3-year-olds
Robertson, Bedford and Mackey <sup>1</sup>	—	1.75	1.70	1.64
Grisdale <sup>2</sup> ... ..	1.68	1.90	2.53	2.28
Simpson, Foster and Christensen <sup>3</sup>	1.55	1.80	2.12	1.57
Average... ..	1.61	1.85	2.12	1.83

From these figures it would appear that the average amount of weight gained per day increases up to about two years old and then diminishes again as maturity is reached.

The effect of age on the proportional development of the body is well-marked and can be seen by a comparison of the figures given under "Average of all breeds" at the end of Table V and the "Average of all cross-breeds" at the end of Table XVI as well as in the breeds and crosses shown in roman type in these two tables. Hatai<sup>4</sup> who studied the percentage growth of various organs in the rat found that the proportional development of the body varied considerably at different ages. The effect of age in the proportional development is as follows:

**Carcase.** Steers and heifers at 33 months old show a larger proportion of carcass (about .4 % more) than do those of 22 months old. Ritzman<sup>5</sup>, who studied the records of the slaughter tests at the International Live Stock Exposition for 1901-1905 at Chicago, found that yearlings dressed at 64.41 % carcass as compared with two-year-olds at 65.40 % carcass. Simpson, Foster and Christensen<sup>6</sup> however found that in ordinary commercial stock the percentage carcass weight was lower for three-year-olds than for two-year-olds; their figures being: calves 57.08 %, yearlings 59.24 %, two-year-olds 58.72 %, three-year-olds 57.59 %, but the numbers on which they based their conclusions were small.

**Suet fat.** With both sexes there is an increase in the proportion of suet fat with age, an increase of a little over .1 % on the average from 22 to 33 months of age.

**Gut fat.** The proportion of gut fat also increases with the advance in age by about .2 % for steers and slightly more for heifers. Ritzman<sup>5</sup>

<sup>1</sup> Robertson, Bedford and Mackey. *Canada Exp. Farms Reports*, p. 292, 1905.

<sup>2</sup> Grisdale. *Canada Exp. Farms Reports*, p. 63, 1904.

<sup>3</sup> Simpson, Foster and Christensen. *New Mexico Sta. Bul.*, No. 103, 1916.

<sup>4</sup> Hatai. *Amer. Journ. Anat.*, Vol. 15, No. 1, 1913-14.

<sup>5</sup> Ritzman. *U.S. Dept. of Agr., Bur. of Animal Industry Rpt.*, 1907.

<sup>6</sup> Simpson, Foster and Christensen. *New Mexico Sta. Bul.*, No. 103, 1916.



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found that yearlings gave 5.94 % tallow while two-year-olds gave 6.42 %. Haecker<sup>1</sup> who studied the composition of the bodies of steers at different stages of growth found that there was little gain of fat until a body weight of 600 lbs. was reached, after which the gain was rapid.

*Tongue and tail.* The proportion of tongue as compared with the rest of the body decreases with age, that is, it reaches its full size quicker than the other parts of the body.

*Head.* The proportions of the head decrease with age in steers by about .3 % between the ages of 22 and 33 months; with heifers the decrease is not so marked. As bone constitutes the bulk of this organ (legs are included under this heading) it may be inferred that the proportions of the skeleton generally, as compared with the rest of the body, decrease between the ages of 22 and 33 months.

Tridon<sup>2</sup> found that the percentage of bone in calves decreased as the age increased and Hunziker and Caldwell<sup>3</sup> also found that as calves advance in age the heavier they become in relation to their height, that is bone or height development takes place first.

Eckles, Reed and Regan<sup>4</sup>, who investigated the growth of dairy heifers, concluded that an animal reaches maturity in skeletal growth very much sooner than it reaches maturity in weight. This, together with the fact (see under Sex above) that heifers reach maturity quicker than steers, confirms the statement above that the proportion of head decreases with age between 22 and 33 months in steers but that the decrease in heifers is not so marked.

*Heart.* With steers the relative size of the heart decreases with age and with heifers also there is a decrease with advancing age but it is only a slight one.

*Tripe.* The relative amount of tripe in both sexes is less at 33 months old than at 22 months old by about .7 %. Müller's<sup>5</sup> statement that there is no relation between the weight or volume of the digestive organs and early maturity is confirmed by a comparison of Table VIII with Table C; the breeds which are early maturing do not show the highest percentage of tripe or intestines.

*Hide.* Hide also shows a smaller proportional development at 33 months than at 22 months of age, the difference being about .5 %.

<sup>1</sup> Haecker. *Minnesota Sta. Rept.*, 1913.

<sup>2</sup> Tridon. *L'Hygiène d. l. Viande et du Lait*, Year 8, No. 1, Jan. 1914.

<sup>3</sup> Hunziker and Caldwell. *Indiana Sta. Bul.*, No. 193, 1916.

<sup>4</sup> Eckles, Reed and Regan. *Missouri Sta. Bul.*, No. 131, 1915.

<sup>5</sup> Müller. *Deut. Landw. Tierzucht*, No. 1, 1914.

*Blood.* The figures for blood are not very reliable as only a few examples have been obtained. They indicate however that the proportion of blood decreases in the steer with age but in the heifer remains about the same.

*Intestines.* The relative proportion of the intestines remains about the same in the steer but increases slightly in the heifer with increase in age from 22 to 33 months. Auernheimer<sup>1</sup> studied the changes in size of the visceral organs of cattle, but I have been unable to obtain his paper.

*Unaccounted for.* With the advance in age from 22 to 33 months the percentage of the animal unaccounted for seems to increase for steers but to decrease for heifers.

The changes in the proportions of the body due to advance in age from 22 to 33 months may be summarised as follows:—With increased age there is an increased proportion of carcase, suet fat, gut fat and intestines (in heifers only) together with a decreased proportion of tongue, head, heart, tripe, hide and blood (in steers only). This confirms the work of Lawes and Gilbert<sup>2</sup>.

#### *Cross-breeding.*

Table IX gives the average weights of all cross-bred cattle exhibited at the Smithfield Show during the period under consideration. All second and doubtful crosses have been excluded from these results.

In order to compare the rate of growth in weight with that of the pure breeds, the figures given have been corrected for age and in Table X are all shown as calculated to 22 and 33 months old.

In only a few of the crosses however are the figures conclusive owing to the small numbers of each cross exhibited and although all the figures are given only those which are considered reliable are referred to below.

If these averages are compared with those shown in Table II for the pure breeds it will be seen that there is no evidence to show that crossing increases the weight; no cross shown in the table exceeds in eventual weight the heavier of its parent breed, although some show more early maturity.

Regarding the inheritance of size, Table XI, which gives the mean of the averages between the breeds crossed, should be compared with Table X which gives the average of the cross-bred animals exhibited. It will be seen that where two large breeds are crossed together the cross

<sup>1</sup> Auernheimer. *Ztschr. Fleisch- u. Milch-hyg.*, No. 12, 1910.

<sup>2</sup> Lawes and Gilbert. *Journ. Roy. Agric. Soc.*, Vol. 21, 1860.

Table IX. *Weights of cross-bred cattle shown at Smithfield, 1893-1913*

Age in months and weeks. Weight in lbs. and decimals of a lb.

Cross		Steers						Heifers							
		Under 2 years			2-3 years			Under 2 years			2-3 years				
		No.	Age	Wt	No.	Age	Wt	No.	Age	Wt	No.	Age	Wt		
♂	♀														
Shorthorn × Red Poll	...	—	—	—	1	35.0	1946.0	—	—	—	1	31.1	1834.0	184.4	
Red Poll × Shorthorn	...	—	—	—	1	34.2	1964.0	—	—	—	—	—	—	—	
Shorthorn × Galloway	...	15	22.0	1437.5	27	33.1	1795.4	10	21.3	1268.5	16	32.1	1901.0	190.1	
Galloway × Shorthorn	...	1	22.0	1441.0	4	31.1	1845.7	—	—	—	4	35.0	1951.0	195.1	
Shorthorn × Welsh	...	—	—	—	—	—	—	—	—	—	5	32.3	1851.0	185.1	
Welsh × Shorthorn	...	—	—	—	1	35.0	1825.0	—	—	—	—	—	—	—	
Shorthorn × Sussex	...	1	20.3	1434.0	—	—	—	—	—	—	—	—	—	—	
Sussex × Shorthorn	...	2	23.0	1572.5	—	—	—	—	—	—	1	34.0	1801.0	180.1	
Shorthorn × Devon	...	—	—	—	—	—	—	—	—	—	3	32.1	1801.0	180.1	
Devon × Shorthorn	...	—	—	—	2	31.3	1677.5	—	—	—	—	—	—	—	
Shorthorn × Aberdeen Angus	57	22.2	1430.3	42	33.0	1844.0	43	22.0	1306.2	32	33.1	1871.0	187.1	187.1	
Aberdeen Angus × Shorthorn	49	22.1	1449.1	46	33.0	1799.6	32	22.1	1339.2	44	31.1	1801.0	180.1	180.1	
Aberdeen Angus × Hereford	...	2	22.2	1379.5	3	33.1	1655.0	1	20.2	1578.0	2	29.1	1621.0	162.1	162.1
Hereford × Aberdeen Angus	...	—	—	—	2	33.3	1717.5	—	—	—	2	32.0	1801.0	180.1	180.1
Aberdeen Angus × Sussex	...	1	20.4	1388.0	—	—	—	1	20.2	1094.0	3	31.3	1801.0	180.1	180.1
Sussex × Aberdeen Angus	...	2	23.0	1440.0	—	—	—	—	—	—	—	—	—	—	—
Aberdeen Angus × Devon	...	1	22.2	1385.0	—	—	—	—	—	—	1	34.1	1801.0	180.1	180.1
Devon × Aberdeen Angus	...	9	23.0	1301.8	4	35.2	1721.5	13	22.3	1222.2	3	34.0	1801.0	180.1	180.1
Kerry × Aberdeen Angus	...	—	—	—	1	31.0	1320.0	—	—	—	—	—	—	—	—
Aberdeen Angus × Kerry	...	—	—	—	4	33.2	1257.0	1	21.3	897.0	10	32.3	1801.0	180.1	180.1
Aberdeen Angus × Dexter	...	23	21.3	915.1	22	32.2	1126.7	19	21.2	911.5	30	32.2	1801.0	180.1	180.1
Dexter × Aberdeen Angus	...	1	24.0	864.0	1	30.0	817.0	—	—	—	3	32.1	1801.0	180.1	180.1
Shorthorn × Dexter	...	13	20.0	902.5	15	32.1	1136.4	6	20.2	931.2	11	31.3	1801.0	180.1	180.1
Dexter × Shorthorn	...	5	19.2	914.4	8	30.1	1094.4	—	—	—	5	29.0	1801.0	180.1	180.1
Kerry × Dexter	...	1	23.2	784.2	2	32.1	952.0	—	—	—	1	34.0	1801.0	180.1	180.1
Dexter × Kerry	...	—	—	—	1	29.0	865.0	2	22.1	739.0	1	33.2	1801.0	180.1	180.1
Shorthorn × Highland	...	1	24.0	1532.0	4	32.0	1684.5	2	22.3	1260.0	2	30.0	1801.0	180.1	180.1
Shorthorn × Ayrshire	...	2	19.1	1228.5	—	—	—	1	21.1	1056.0	—	—	—	—	—
Aberdeen Angus × Galloway	...	—	—	—	1	34.0	2076.0	—	—	—	—	—	—	—	—
Aberdeen Angus × Ayrshire	...	1	23.3	1204.0	2	31.0	1775.0	—	—	—	—	—	—	—	—
Aberdeen Angus × Lincoln Red	...	—	—	—	—	—	—	1	21.2	1222.0	1	33.2	1801.0	180.1	180.1
Galloway × Ayrshire	...	—	—	—	1	32.1	1176.0	1	20.0	1124.0	1	31.2	1801.0	180.1	180.1
Galloway × Highland	...	—	—	—	3	31.1	1186.0	1	18.1	840.0	—	—	—	—	—
Hereford × Galloway	...	2	22.0	1188.0	—	—	—	1	23.3	1001.0	1	35.0	1951.0	195.1	195.1
Hereford × Shorthorn	...	2	21.2	1188.0	1	34.1	2066.0	—	—	—	3	33.0	1801.0	180.1	180.1
Devon × South Devon	...	—	—	—	—	—	—	—	—	—	2	33.1	1801.0	180.1	180.1
Sussex × Red Poll	...	—	—	—	—	—	—	—	—	—	1	33.3	1801.0	180.1	180.1
Sussex × Dutch	...	1	23.2	1018.0	—	—	—	—	—	—	—	—	—	—	—
Sussex × Jersey	...	1	24.0	1075.0	—	—	—	—	—	—	—	—	—	—	—
Hereford × Kerry	...	—	—	—	—	—	—	—	—	—	1	35.0	1951.0	195.1	195.1
Shorthorn × Kerry	...	—	—	—	2	34.1	1312.5	2	20.2	1075.5	—	—	—	—	—
Hereford × Dexter	...	4	20.3	951.0	4	30.3	1157.2	—	—	—	2	32.2	1801.0	180.1	180.1
Red Poll × Dexter	...	1	22.1	884.0	—	—	—	—	—	—	1	30.1	1801.0	180.1	180.1
Galloway × Dexter	...	—	—	—	—	—	—	—	—	—	1	26.6	1801.0	180.1	180.1
Devon × Dexter	...	—	—	—	1	26.0	1064.0	—	—	—	2	31.3	1801.0	180.1	180.1
Sussex × Dexter	...	—	—	—	—	—	—	—	—	—	1	31.1	1801.0	180.1	180.1
Dexter × Jersey	...	1	21.1	860.0	—	—	—	—	—	—	—	—	—	—	—

Table X. *Comparative weights of cross-bred cattle.*

Weights in lbs. and decimals of a lb.

Cross		22 months				33 months			
		Steers		Heifers		Steers		Heifers	
		No.	Weight	No.	Weight	No.	Weight	No.	Weight
♂	♀								
Shorthorn × Red Poll...	...	—	—	—	—	1	1834.8	1	1786.5
Red Poll × Shorthorn...	...	—	—	1	1331.0	1	1878.8	—	—
Shorthorn × Galloway...	...	15	1437.5	10	1283.1	27	1781.9	16	1639.4
Galloway × Shorthorn...	...	1	1441.0	—	—	4	1949.3	4	1439.5
Shorthorn × Welsh...	...	—	—	—	—	—	—	5	1297.2
Welsh × Shorthorn...	...	—	—	—	—	1	1721.0	—	—
Shorthorn × Sussex...	...	1	1520.0	—	—	—	—	—	—
Sussex × Shorthorn...	...	2	1504.2	—	—	—	—	1	1461.7
Shorthorn × Devon...	...	—	—	—	—	—	—	3	1405.1
Devon × Shorthorn...	...	—	—	—	—	2	1743.5	—	—
Shorthorn × Aberdeen Angus	...	57	1398.7	43	1306.2	42	1844.0	32	1742.5
Aberdeen Angus × Shorthorn	...	49	1432.8	32	1324.2	46	1799.6	44	1593.7
Aberdeen Angus × Hereford	...	2	1348.9	1	1693.2	3	1642.6	2	1388.0
Hereford × Aberdeen Angus	...	—	—	—	—	2	1282.4	2	1405.6
Aberdeen Angus × Sussex...	...	1	1454.0	1	1173.8	—	—	3	1577.5
Sussex × Aberdeen Angus	...	2	1377.6	—	—	—	—	—	—
Aberdeen Angus × Devon...	...	1	1354.4	—	—	—	—	1	1653.5
Devon × Aberdeen Angus	...	9	1245.4	13	1182.0	1	1699.5	3	1513.7
Kerry × Aberdeen Angus	...	—	—	—	—	1	1494.8	1	1132.0
Aberdeen Angus × Kerry	...	—	—	1	997.3	1	1238.2	10	1171.1
Aberdeen Angus × Dexter	...	23	925.6	19	932.8	22	1143.9	30	1132.4
Dexter × Aberdeen Angus	...	1	792.0	—	—	1	898.6	3	1104.9
Shorthorn × Dexter...	...	18	993.0	6	999.0	15	1162.8	11	1169.2
Dexter × Shorthorn...	...	5	1031.4	—	—	8	1193.4	5	1150.0
Kerry × Dexter...	...	1	734.2	—	—	2	971.2	1	936.6
Dexter × Kerry...	...	—	—	2	730.7	1	985.0	1	969.4
Shorthorn × Highland...	...	1	1404.8	2	1218.6	4	1736.9	2	1758.1
Shorthorn × Ayrshire...	...	2	1403.4	1	1093.2	—	—	—	—
Aberdeen Angus × Galloway...	...	—	—	—	—	1	2014.8	—	—
Aberdeen Angus × Ayrshire...	...	1	1115.1	—	—	2	1889.4	—	—
Aberdeen Angus × Lincoln Red	...	—	—	1	1250.4	—	—	1	1757.2
Galloway × Ayrshire...	...	—	—	1	1236.0	1	1293.3	1	1158.8
Galloway × Highland...	...	—	—	1	1012.5	3	1252.3	—	—
Hereford × Galloway...	...	2	1188.0	1	927.5	—	—	1	880.4
Hereford × Shorthorn...	...	2	1215.6	—	—	1	2005.6	3	1536.3
Devon × South Devon	...	—	—	—	—	—	—	2	1727.9
Sussex × Red Poll...	...	—	—	—	—	—	—	1	1595.7
Sussex × Dutch...	...	1	953.2	—	—	—	—	—	—
Sussex × Jersey...	...	1	988.4	—	—	—	—	—	—
Hereford × Kerry...	...	—	—	—	—	—	—	1	1408.8
Shorthorn × Kerry...	...	—	—	2	1059.3	2	1264.5	—	—
Hereford × Dexter...	...	4	1008.2	—	—	4	1241.8	2	1314.4
Red Poll × Dexter...	...	1	874.1	—	—	—	—	1	1003.6
Galloway × Dexter...	...	—	—	—	—	—	—	1	1634.0
Devon × Dexter...	...	—	—	—	—	1	1349.6	2	916.0
Sussex × Dexter...	...	—	—	—	—	—	—	1	1096.7
Dexter × Jersey...	...	1	890.3	—	—	—	—	—	—

266 *Relative Growth and Development of Cattle*Table XI. *Mean weights between breeds for comparison with Table X.*

Breeds	In lbs.			
	22 months		33 months	
	Steers	Heifers	Steers	Heifers
Shorthorn—Galloway ...	1314.7	1293.7	1728.6	1519.0
Shorthorn—Aberdeen Angus	1386.0	1302.8	1787.2	1644.1
Devon—Aberdeen Angus ...	1289.8	1265.6	1642.9	1504.7
Aberdeen Angus—Kerry ...	1061.1	1103.5	1431.8	1293.7
Aberdeen Angus—Dexter ...	1090.6	1043.8	1402.0	1259.3
Shorthorn—Dexter ...	1115.0	1057.8	1444.2	1304.0

is usually heavier than the mean of the two parent breeds (the Devon-Aberdeen Angus cross is slightly lighter). When a large breed is crossed with a small one the cross is not so heavy as the mean of the parent breeds, and this holds whichever way the cross is made.

In the first case (two large breeds) it may be that size is intermediate in the first generation but that the increased vitality of a cross causes increase in weight. Should such a condition exist in the second case (a large breed crossed with a small one), small size would appear to be slightly dominant in the first generation.

Punnett and Bailey<sup>1</sup> found that with rabbits inbreeding led to a diminution in weight and it may be that in cattle an outcross has the effect of increasing size through increasing vitality. Gowen<sup>2</sup> who has experimentally crossed dairy and beef types of cattle has not yet published an account of the weights attained by the cross.

The numbers from which the results have been calculated are so small that it is difficult to determine the effect of reciprocal crosses. The results of the Shorthorn-Aberdeen Angus cross however, in view of the numbers exhibited, probably show a reliable result.

At 22 months old the progeny of the Shorthorn bull crossed with the Aberdeen Angus cow does not grow so quickly as the reciprocal cross, whereas at 33 months old the positions are changed and this cross puts on weight more quickly than the reciprocal cross. This is clearly seen in Table XIII, the cross Aberdeen Angus bull and Shorthorn cow being more early maturing than the reciprocal cross.

This remarkable result is in evidence not only with the steers but also with the heifers and it is hoped that opportunity may occur for a more extensive analysis of this point.

Punnett and Bailey<sup>1</sup> have shown that in the rabbit size and early

<sup>1</sup> Punnett and Bailey. *Journ. Genetics*, Vol. 8, No. 1, Dec. 1918.

<sup>2</sup> Gowen. *Journ. Agr. Research*, Vol. 15, No. 1, 1918.

maturity are transmitted independently and it may be that they behave as sex-linked characters in cattle.

Crossing tends to obliterate sexual differences. The sexual differences are very much smaller in the cross-breeds (see Table XII) than in the pure breeds (Table VII) especially at 33 months of age. The reason for this may be that the whole sexual vitality is lowered and not only the reproduction cells themselves are affected (as the well-known sterility of crosses shows) but also the secondary sexual characters are affected and lessened in amount.

Table XII. *Cross-bred cattle—relative weights of the sexes.*

Cross		22 months				33 months			
		Steers		Heifers		Steers		Heifers	
		No.	Weight	No.	Weight	No.	Weight	No.	Weight
Shorthorn × Galloway ...	♂	15	100	10	89.3	27	100	16	92.0
Shorthorn × Aberdeen Angus	♀	57	100	43	93.4	42	100	32	94.5
Aberdeen Angus × Shorthorn		49	100	32	92.4	45	100	44	88.5
Devon × Aberdeen Angus ...		9	100	13	94.9	4	100	3	94.6
Aberdeen Angus × Kerry ...		—	—	1	—	4	100	19	94.8
Aberdeen Angus × Dexter ...		23	100	19	100.8	22	100	30	98.9
Dexter × Shorthorn ...		5	—	—	—	8	100	5	96.3
Shorthorn × Dexter ...		18	100	6	100.5	15	100	11	100.5

The small sexual difference (in weight) of crosses is particularly marked when crosses between large and small breeds are considered. Darwin's finding that "the more distant the relation in crossing the less fertile the cross" is in this case extended to decreased secondary sexual characters, even though it may not be shown in lessened fertility.

It will be noticed also in this table (Table XII) that in cross-breeds (with two exceptions) the sexual differences do not increase with age as is the case with the pure breeds (Table IV).

Table XIII. *Cross-bred cattle—relative weights at different ages.*

Cross		Steers				Heifers			
		22 months		33 months		22 months		33 months	
		No.	Weight	No.	Weight	No.	Weight	No.	Weight
Shorthorn × Galloway ...	♂	15	80.6	27	100	10	78.2	16	100
Shorthorn × Aberdeen Angus	♀	57	75.8	42	100	43	74.9	32	100
Aberdeen Angus × Shorthorn		49	79.6	45	100	32	83.8	44	100
Devon × Aberdeen Angus ...		9	77.5	4	100	13	78.1	3	100
Aberdeen Angus × Kerry ...		—	—	1	—	1	77.3	19	100
Aberdeen Angus × Dexter ...		23	80.9	22	100	19	82.3	30	100
Dexter × Shorthorn ...		5	86.4	8	100	—	—	5	—
Shorthorn × Dexter ...		18	85.4	15	100	—	85.5	11	100

Table XIV. Carcase weights of cross-bred cattle shown at Smithfield, 1893-1913.

Ages in months and weeks. Weights in lbs. and decimals of a lb.																
Cross	Sex	Age	No.	Average	Live weight	Carcase weight	Suet fat	Gut fat	Tongue	Head	Heart	Tripe	Hide	Blood	In- testine	Unac- counted
Shorthorn x Galloway	Steers	Under 2 yrs	7	20.3	1259.1	795.7	17.9	33.7	10.1	51.3	35.5	106.6	82.3	[28.7]	16.4	109.6
	Steers	2-3 yrs	3	32.3	1512.7	1121.0	31.7	84.0	15.7	64.3	41.0	139.0	99.0	[39.7]	22.7	187.3
	Heifers	Under 2 yrs	2	20.0	1168.0	701.5	18.5	33.5	10.5	41.0	30.0	89.0	71.5	—	15.5	94.0
	Heifers	2-3 yrs	3	32.2	1400.7	904.0	25.0	43.0	11.3	47.3	34.7	111.0	78.7	[28.0]	20.3	125.3
Galloway x Shorthorn	Steers	Under 2 yrs	2	22.1	1150.0	731.5	16.0	33.5	10.5	51.0	34.0	92.0	84.5	[33.0]	15.5	90.5
	Steers	2-3 yrs	3	33.0	1298.0	770.0	17.0	22.0	9.0	54.0	39.0	137.0	95.0	—	17.0	160.0
	Heifers	Under 2 yrs	1	22.3	1076.0	682.0	17.0	20.0	8.0	33.0	44.0	112.0	65.0	—	15.0	81.0
	Heifers	2-3 yrs	1	28.1	1036.0	605.0	16.0	23.0	7.0	42.0	30.0	94.0	60.0	—	15.0	85.0
Shorthorn x Sussex	Steers	2-3 yrs	1	31.4	1805.0	1188.0	24.0	80.0	15.0	62.0	40.0	117.0	94.0	[41.0]	20.0	167.0
	Heifers	Under 2 yrs	1	22.4	1110.0	698.0	14.0	17.0	10.0	47.0	30.0	129.0	71.0	[30.0]	15.0	109.0
	Steers	Under 2 yrs	1	22.3	1295.0	860.0	18.0	34.0	11.0	50.0	29.0	98.0	84.0	—	13.0	98.0
	Heifers	2-3 yrs	1	34.0	1398.0	940.0	23.0	50.0	10.0	47.0	34.0	104.0	84.0	—	19.0	87.0
Shorthorn x A. Angus	Steers	Under 2 yrs	13	21.2	1272.4	833.2	19.2	36.1	10.8	52.7	33.9	102.2	80.1	[20.5]	17.0	87.2
	Steers	2-3 yrs	12	33.1	1486.2	977.0	23.0	29.4	11.7	56.8	39.5	110.3	88.9	[29.0]	19.8	112.8
	Heifers	Under 2 yrs	5	21.3	1166.0	746.4	19.2	27.4	10.6	41.8	33.0	106.0	68.4	—	19.2	91.0
	Heifers	2-3 yrs	6	30.1	1367.0	899.7	23.0	50.8	12.8	48.0	38.2	92.2	73.5	[28.5]	22.2	107.6
A. Angus x Shorthorn	Steers	Under 2 yrs	17	21.1	1255.5	813.6	19.0	31.9	10.6	51.8	35.6	98.4	77.0	[33.3]	17.1	100.5
	Steers	2-3 yrs	14	32.5	1451.1	955.5	23.4	38.2	11.1	53.0	39.6	113.6	82.0	[29.0]	20.8	120.5
	Heifers	Under 2 yrs	5	27.0	1182.0	769.0	19.0	29.6	9.8	45.6	35.4	96.3	71.8	—	19.8	106.8
	Heifers	2-3 yrs	12	31.2	1389.9	877.7	24.2	36.3	11.8	47.2	37.1	110.6	74.2	—	19.8	100.4
A. Angus x Hereford	Steers	Under 2 yrs	5	20.3	1286.6	821.2	16.4	35.2	11.8	52.0	32.8	96.4	86.8	[25.0]	15.4	118.6
	Steers	2-3 yrs	1	32.3	1788.0	1214.0	30.0	53.0	13.0	64.0	41.0	131.0	109.0	[35.0]	27.0	166.0
	Heifers	Under 2 yrs	2	19.2	1117.5	706.5	13.5	23.5	10.5	44.5	30.5	96.5	68.5	[18.0]	19.5	102.0
	Heifers	2-3 yrs	1	27.2	1202.0	760.0	14.0	29.0	14.0	45.0	35.0	102.0	68.0	[27.0]	17.0	118.0
Hereford x A. Angus	Steers	Under 2 yrs	3	20.0	1104.3	711.3	14.7	19.7	10.0	47.7	31.0	88.7	80.0	—	16.0	85.2
	Steers	Under 2 yrs	3	21.3	1079.7	679.3	14.3	29.7	10.0	45.7	29.7	94.7	70.7	[12.0]	13.7	91.0
	Steers	2-3 yrs	3	32.0	1200.7	759.7	17.7	37.0	9.7	48.7	29.7	82.3	78.0	—	16.0	88.0
	Heifers	Under 2 yrs	1	27.0	1252.0	812.0	21.0	38.0	11.0	49.0	31.0	88.0	94.0	—	17.0	97.0

Dexter x Shorthorn	1	29.4	1222.0	732.0	22.0	60.0	11.0	45.0	31.0	82.0	81.0	[28.0]	17.0	140.0
Shorthorn x Red Poll	1	17.4	1071.0	645.0	16.0	28.0	9.0	43.0	35.0	113.0	68.0	—	17.0	97.0
Shorthorn x Welsh	1	26.2	1039.0	623.0	19.0	25.0	12.0	43.0	30.0	104.0	82.0	—	15.0	86.0
Shorthorn x Highland	2	31.1	1379.5	904.0	19.0	40.0	11.5	57.0	34.0	83.5	106.0	[31.0]	19.0	105.5
Shorthorn x Kerry	1	22.1	1169.0	750.0	21.0	46.0	11.0	47.0	36.0	89.0	71.0	[28.0]	20.0	87.0
Heifers	2	32.2	1404.5	926.0	20.0	40.5	11.5	51.5	35.0	93.0	83.0	[30.0]	17.5	124.5
Heifers	2	33.0	1357.0	892.0	25.0	39.5	11.5	47.0	37.0	99.5	76.0	[31.0]	19.0	110.5
Steers	2	33.3	1395.5	901.5	25.0	46.5	11.5	51.0	41.5	94.0	83.5	[29.0]	21.0	120.0
Heifers	2	28.3	1211.0	737.0	29.0	39.0	10.5	45.5	37.0	86.0	77.0	—	20.0	83.0
Steers	2	21.2	1100.0	712.5	19.0	36.5	8.0	43.5	36.0	72.0	68.0	—	18.0	86.5
A. Angus x Dexter	1	33.4	1066.0	641.0	29.0	39.0	10.0	43.0	27.0	85.0	78.0	—	17.0	96.0
Heifers	3	36.2	1010.0	623.7	17.7	24.3	9.0	37.7	30.3	88.0	60.7	—	17.0	101.5
A. Angus x Sussex	1	23.3	1324.0	801.0	15.0	33.0	11.0	48.0	33.0	134.0	84.0	[30.0]	16.0	149.0
A. Angus x Highland	3	29.1	1658.3	721.7	17.7	22.0	9.0	42.3	28.0	82.7	74.0	—	13.3	47.6
Galloway x Highland	1	22.3	1605.0	644.0	11.0	19.0	10.0	50.0	26.0	87.0	78.0	—	9.0	71.0
Galloway x A. Angus	1	31.1	1283.0	820.0	17.0	52.0	13.0	50.0	32.0	88.0	86.0	[31.0]	13.0	112.0
Galloway x A. Angus	1	21.1	1030.0	650.0	14.0	25.0	9.0	37.0	30.0	74.0	57.0	—	13.0	121.0
Galloway x A. Angus	1	34.1	1332.0	922.0	24.0	56.0	12.0	47.0	32.0	79.0	71.0	—	18.0	91.0
Galloway x Ayleshire	1	34.3	1074.0	619.0	27.0	37.0	7.0	40.0	36.0	98.0	57.0	—	23.0	80.0
Devon x A. Angus	1	24.0	1233.0	850.0	20.0	26.0	10.0	44.0	33.0	70.0	75.0	—	15.0	90.0
Devon x A. Angus	1	23.1	1192.0	779.0	19.0	28.0	9.0	39.0	29.0	107.0	79.0	—	15.0	89.0
Red Poll x Friesian	1	22.2	1135.0	739.0	15.0	29.0	9.0	46.0	31.0	90.0	72.0	—	17.0	87.0



Table XV. Comparative carcass weights of cross-bred cattle.

		Weights in lbs. and decimals of a lb.										
Cross	Sex	Age mths	No.	Live weight			Carcass			Weights		
				fat	Suet	Gut	Tongue	Head	Heart	Tyre	Hide	Blood
Shorthorn × Galloway	Steers	22	7	1334.6	843.6	18.9	35.7	10.7	51.3	112.9	87.2	[30.4]
	Steers	33	3	1826.5	1139.6	31.9	84.6	12.8	64.8	41.3	140.0	99.7
	Heifers	22	2	1218.8	771.6	20.3	36.8	11.5	48.4	33.0	97.9	78.6
Galloway × Shorthorn	Heifers	33	3	1422.2	917.9	25.4	43.6	11.4	48.0	35.2	112.5	79.9
	Steers	22	2	1146.0	723.3	15.8	33.1	10.4	50.4	33.6	91.0	83.6
	Steers	33	1	1266.0	770.0	17.0	22.0	9.0	54.0	38.0	137.0	95.0
Shorthorn × Sussex	Heifers	22	1	1040.6	659.5	16.5	19.3	7.8	31.0	42.6	108.4	62.9
	Heifers	33	1	1208.9	777.1	17.5	25.8	8.1	49.2	36.4	109.5	69.3
	Steers	33	1	1720.2	1132.8	22.8	76.3	12.4	59.4	38.1	101.6	89.6
Sussex × Shorthorn	Heifers	22	1	1061.8	639.0	13.4	16.3	9.6	45.0	28.7	123.4	67.9
	Heifers	22	1	1252.4	831.8	17.4	32.9	10.7	48.4	28.1	94.8	81.3
	Heifers	33	1	1357.0	912.4	22.4	48.6	9.7	45.7	33.0	101.0	81.6
Shorthorn × A. Angus	Steers	22	13	1302.0	862.6	19.6	36.9	11.0	53.9	34.7	104.6	82.8
	Steers	33	12	1475.1	979.6	22.8	36.1	11.6	56.4	38.2	108.5	86.2
	Heifers	22	5	1179.4	755.0	19.4	27.7	10.7	45.3	33.4	107.2	69.2
A. Angus × Shorthorn	Heifers	33	6	1491.3	981.1	25.1	35.4	13.9	52.4	41.4	106.5	78.1
	Steers	22	17	1209.6	842.1	19.6	33.0	10.9	53.6	36.8	101.8	79.7
	Steers	33	14	1473.3	970.1	23.7	38.5	11.3	53.8	40.2	115.3	83.8
A. Angus × Hereford	Heifers	22	5	1238.2	806.2	19.8	30.9	10.2	37.3	33.9	101.2	75.0
	Heifers	33	12	1403.6	919.1	25.4	38.0	12.3	49.4	39.5	115.8	77.6
	Steers	22	5	1364.1	870.5	17.4	37.3	12.5	55.1	34.8	102.2	92.0
Hereford × A. Angus	Heifers	33	1	1801.6	1223.3	30.2	53.4	13.1	64.5	41.5	162.8	109.8
	Heifers	22	2	1260.8	797.1	15.2	23.1	11.8	50.2	34.4	108.3	77.8
	Heifers	33	1	1442.4	912.0	16.8	34.8	16.8	51.0	42.0	122.4	81.6
Hereford × A. Angus	Steers	22	3	1214.7	782.4	16.1	21.6	10.9	52.4	34.0	97.9	80.0
	Steers	33	1	1442.4	912.0	16.8	34.8	16.8	51.0	42.0	122.4	81.6
	Steers	22	3	1214.7	782.4	16.1	21.6	10.9	52.4	34.0	97.9	80.0

Unac-  
counted  
forIn-  
testine

Blood

Hide

Tyre

Heart

Head

Tongue

Gut

Suet

fat

Live weight

Carcass

Weights

in lbs. and decimals of a lb.

Table XV.

Comparative carcass weights of cross-bred cattle.

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Shorthorn × Dexter	22	3	1092.1	687.1	14.5	30.0	10.1	40.2	30.0	95.8	71.5	[27.3]	13.9	93.0
	33	3	1238.3	892.4	23.5	38.2	16.0	60.2	30.6	85.0	60.4	—	16.7	101.3
Heifers	22	1	997.2	644.2	17.8	29.2	12.5	37.6	27.2	66.0	—	—	19.8	75.9
	33	1	1470.7	966.1	27.4	43.1	12.6	52.8	35.9	100.1	104.6	—	27.4	100.7
Steers	33	1	1344.2	805.2	24.2	65.0	12.1	50.6	34.7	90.2	89.1	[30.8]	18.7	154.0
Dexter × Shorthorn	22	1	1300.0	788.0	19.5	35.0	10.9	52.6	43.0	148.1	83.0	—	20.7	108.2
Shorthorn × Red Poll	22	1	897.6	537.6	16.5	27.7	10.5	37.1	26.0	89.9	70.8	—	13.1	74.4
Shorthorn × Welsh	22	1	1456.7	954.4	30.0	42.2	12.1	59.9	35.9	88.1	111.9	[32.7]	20.0	112.2
Shorthorn × Highland	22	1	1155.9	741.0	20.7	45.5	10.9	46.6	35.6	79.1	70.2	[27.7]	18.8	87.6
Shorthorn × Kerry	33	2	1425.1	940.2	20.3	47.1	11.6	52.3	36.5	94.4	84.2	[30.6]	17.7	128.8
	33	2	1357.0	892.0	25.0	39.5	11.5	47.0	37.0	99.5	76.0	[31.0]	19.0	110.5
Heifers	33	2	1364.6	881.6	24.4	45.5	11.2	49.9	40.6	92.0	81.7	[28.3]	20.6	117.1
Steers	33	2	1385.6	902.6	29.4	44.1	12.0	52.3	42.1	98.2	88.5	—	22.3	98.0
Heifers	33	2	1125.6	729.1	19.4	37.3	8.2	44.5	36.8	73.7	60.6	—	18.4	83.6
Steers	33	1	1034.8	625.2	28.2	37.8	9.7	43.7	26.2	82.5	77.8	—	16.5	90.2
Heifers	33	3	1092.8	674.8	19.1	24.1	9.7	40.8	32.8	95.2	65.7	—	18.4	112.2
Steers	22	1	1226.7	745.2	13.9	30.7	10.3	44.5	30.7	124.2	77.9	[27.8]	14.9	137.4
A. Angus × Sussex	33	3	1193.9	814.2	19.9	25.2	10.7	47.7	31.6	93.2	83.4	—	14.9	53.1
A. Angus × Highland	22	1	971.9	622.8	10.7	18.4	9.7	48.4	25.2	84.2	75.5	—	8.8	68.2
Galloway × Highland	33	1	1354.8	865.9	17.9	34.8	13.8	52.8	33.8	92.9	90.9	[32.7]	13.7	118.3
Galloway × A. Angus	22	1	1066.3	673.0	14.4	25.8	9.3	38.3	31.0	76.6	58.9	—	13.4	125.6
	33	1	1302.8	888.0	23.1	53.8	11.6	49.3	30.5	76.1	68.4	—	17.4	88.3
Galloway × Ayrshire	33	1	1020.1	616.6	25.6	35.2	6.7	37.0	34.1	93.1	54.2	—	21.9	94.8
Devon × A. Angus	22	1	1130.6	770.6	18.4	24.0	9.2	40.4	30.3	64.2	68.8	—	13.8	81.9
Heifers	22	1	1129.0	727.3	18.0	26.5	8.5	37.0	27.5	101.3	74.8	—	14.2	83.9
Red Poll × Hereford	22	1	1109.8	722.6	14.8	28.4	8.9	45.0	30.4	88.0	70.1	—	16.7	84.6



Shorthorn x Dexter	22	3	62.94	1.42	2.75	0.92	4.23	2.75	8.77	6.55	(2.50)	1.27	8.43
Steers	33	3	64.74	1.89	3.03	0.81	4.05	2.47	8.86	6.46	—	1.34	8.21
Heifers	22	1	64.60	1.79	2.93	1.25	3.77	2.73	6.72	6.62	—	1.98	7.91
	33	1	65.70	1.86	2.92	0.86	3.50	2.44	6.81	7.11	—	1.86	6.55
Dexter x Shorthorn	33	1	59.90	1.80	4.01	0.90	3.76	2.53	6.71	6.63	[2.29]	1.39	11.47
Shorthorn x Red Poll	22	1	60.27	1.49	2.97	0.83	4.02	3.25	11.31	6.34	—	1.58	8.21
Heifers	22	1	61.01	1.84	2.42	1.17	4.13	2.90	10.02	7.88	—	1.46	7.17
Shorthorn x Welsh	33	2	65.52	1.73	2.90	0.83	4.11	2.46	6.05	7.67	[2.24]	1.37	7.36
Shorthorn x Kerry	22	1	64.71	1.79	3.93	0.94	4.02	3.08	6.84	6.07	[2.39]	1.62	7.60
Steers	33	2	65.63	1.42	2.83	0.81	3.66	2.48	6.62	5.90	[2.14]	1.24	9.06
Heifers	33	2	65.73	1.70	2.81	0.85	3.46	2.73	7.33	5.60	[2.28]	1.50	8.19
A. Angus x Kerry	33	2	64.61	1.79	3.33	0.82	3.66	2.08	6.74	5.98	[2.07]	1.51	8.58
Heifers	33	2	64.95	2.12	3.17	0.86	3.76	3.03	7.07	6.37	—	1.60	7.06
A. Angus x Dexter	22	2	64.77	1.72	3.31	0.73	3.95	3.37	6.55	6.19	—	1.63	8.88
Steers	33	1	60.13	2.12	2.69	0.94	4.22	2.53	7.97	7.52	—	1.59	8.73
Heifers	33	3	61.74	1.75	2.50	0.88	3.73	3.00	8.71	6.01	—	1.68	10.80
A. Angus x Sussex	22	1	60.42	1.13	2.60	0.85	3.63	2.50	10.12	6.35	[2.27]	1.21	11.29
A. Angus x Highland	33	3	68.20	1.60	2.11	0.89	4.00	2.65	7.81	6.99	—	1.25	4.50
Galloway x Highland	22	1	64.08	1.10	1.59	1.00	4.98	2.59	8.66	7.77	—	0.91	7.02
Galloway x Angus	33	1	63.91	1.32	4.04	1.02	3.09	2.50	6.88	6.71	[2.41]	1.01	9.42
Galloway x A. Angus	22	1	63.12	1.35	2.43	0.87	3.50	2.91	7.18	5.52	—	1.26	11.78
Heifers	33	1	63.16	1.77	4.15	0.89	3.18	2.36	5.84	5.25	—	1.33	6.79
Galloway x Ayrshire	33	1	60.44	2.31	3.45	0.66	3.71	3.34	9.42	5.31	—	2.15	9.31
Devon x A. Angus	22	1	68.05	1.63	2.42	0.81	3.57	2.68	5.68	6.08	—	1.22	7.26
Heifers	22	1	65.31	1.59	2.84	0.75	3.28	2.43	8.97	6.63	—	1.26	7.44
Red Poll x Hereford	22	1	65.11	1.33	2.56	0.80	4.05	2.74	7.93	6.34	—	1.50	7.77
Average of all crosses	22	58	64.60	1.45	2.67	0.86	4.10	2.77	7.97	6.47	(2.50)	1.33	7.64
Steers	33	47	65.44	1.63	2.88	0.89	3.76	2.62	7.45	6.11	(1.86)	1.37	7.94
Heifers	22	20	63.56	1.53	2.46	0.89	3.64	2.86	8.73	6.11	(1.97)	1.50	8.72
	33	34	64.99	1.78	2.98	0.87	3.56	2.79	7.79	5.65	(2.10)	1.57	8.02

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Table XIII shows the rate of early maturity in cross-bred cattle. On the whole heifers show only slightly more early maturing qualities than steers, the difference not being so marked as in pure breeds.

If the results given in Table XIII are compared with those given in Table VIII it will be seen that the general effect of cross-breeding is not as has often been stated to increase the rate of maturity in weight.

With regard to the relative development of cross-bred cattle, the small number of records of "carcase" weights available are shown (as averaged direct from the records of the Show) in Table XIV.

For comparative purposes these have been corrected for age and the results are shown in Table XV.

As with pure breeds the proportions of the various organs in percentage of live weight have been calculated and are shown in Table XVI.

The exact effect of crossing on the proportions of the animal is difficult to determine owing to the small numbers exhibited and the conclusions arrived at below are only tentative and need confirmation.

If the average of all the crosses (shown at the end of Table XVI) is compared with the average for pure breeds (shown at the end of Table V), it will be seen that crosses on the whole give a slightly larger proportion of carcase. The proportion of suet fat is also higher in crosses than in pure breeds with steers but is smaller with heifers, again another example of the blurring of sex differences on crossing. The proportion of gut fat on the whole is greater in cross breeds and so is the proportion of tongue. The proportion of head however is lower in crosses than in pure breeds but the hearts of crosses are proportionately heavier. The amount of tripe in both crosses and pure breeds is about the same.

Pure breeds have distinctly heavier hides than crosses and also on the whole slightly more blood. As with tripe, the proportions of intestines in both crosses and pure breeds is practically the same. Crosses have slightly more weight "unaccounted for" than pure breeds.

These differences may be summarised as follows: cross-breds have a larger proportion of carcase (slightly), suet fat (steers only), gut fat, tongue, heart and "unaccounted for" (slightly) than pure breeds, but pure breeds have a larger proportion of suet fat (heifers only), head, hide, and blood (slightly), while the proportions of tripe and intestine are about the same in each case.

These results, together with those mentioned under Sex (above), lead us to question the advisability of some Breed Societies insisting on great sexual differences being shown between the bull and the cow: especially as the large head of the bull, and large bone and hide development which is correlated with it, leads to waste on slaughter.

*Individual Variation.*

Within the limits of a breed, even when variations due to sex, age, etc. have been eliminated, there still remains a great difference between individuals in their capacity to put on weight. These individual variations are in some cases very large, and the causes for these variations are at present unknown, but the conditions affecting them can be studied.

The "standard deviations" and "coefficients of variability" have been calculated for a few of the best represented breeds and crosses and these are given in Table XVII. It will be seen in the last column of this table that breeds differ in the amount of variability exhibited. Shorthorns show the smallest amount of variability (8.04), and Aberdeen Angus are more variable but not so variable as Welsh (11.98). Reimers<sup>1</sup> has investigated the variability of cattle but his paper I have been unable to obtain.

Table XVII. *Variation in live weight of cattle.*

## (a) STANDARD DEVIATION - LBS.

Breed	Steers				Heifers			
	22 months		33 months		22 months		33 months	
	No.	months	No.	months	No.	months	No.	months
Shorthorn ... ..	187	114	161	144	11	110	118	134
Aberdeen Angus ... ..	193	118	155	162	9	127	155	130
Welsh ... ..	135	119	228	192	8	202	96	177
Aberdeen Angus x Shorthorn	49	128	46	237	32	100	44	177
Shorthorn x Aberdeen Angus	57	108	42	146	43	115	32	149
Average all breeds ... ..	5	117	5	176	2	108	5	133

## (b) COEFFICIENT OF VARIABILITY.

Breed	Steers		Heifers		Breed Average
	22 months	33 months	22 months	33 months	
Shorthorn ... ..	8.12	7.77	8.32	7.94	8.04
Aberdeen Angus ... ..	8.70	9.13	9.82	8.13	8.94
Welsh ... ..	8.68	11.33	16.00	11.93	11.98
Aberdeen Angus x Shorthorn	8.93	13.15	7.57	11.12	10.19
Shorthorn x Aberdeen Angus	7.70	7.92	8.83	8.72	7.29
Average all breeds ... ..	8.43	9.80	8.20	9.57	—

In the only cross-breeds examined there is a difference in the amount of variability depending on the way in which the cross is made. The cross Aberdeen Angus bull x Shorthorn cow gives a much more variable cross than either parent breed, while the reciprocal cross, Shorthorn bull x

<sup>1</sup> Reimers. *Jahrb. Wiss. u. Prakt. Tierzucht*, 1914.

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Aberdeen Angus cow gives a less variable cross than either of the parent breeds. I am informed by Capt. J. W. Stack that in Australia Aberdeen Angus bulls are not favoured by the exporters of meat owing, when crossed with the common stock, to the great variability in size of their offspring. Information I have received from other sources however does not confirm this opinion.

Variation as measured both by the standard deviation and coefficient of variability increases with age both in steers and heifers except in the case of Shorthorns where it decreases slightly with age. That this decrease with age in Shorthorns is not a chance result is confirmed in Table XVIII where it is shown in each period under consideration. Robertson<sup>1</sup> found with children that the variability in weight increases with age between 6 and 14 years but that it decreased with age between 1 and 12 months. It will be seen also from Table XVII that steers are more variable in weight than heifers of the same age. King<sup>2</sup> found with rats that males were more variable than females at the older ages although when young they both showed approximately the same amount of variability.

Table XVIII. *Changes in variation in live weight from 1893 to 1913.*

(a) STANDARD DEVIATION—LBS.								
Breed	Period I		Period II		Period III			
	No.	Weight	No.	Weight	No.	Weight		
Shorthorn steers 22 months	...	...	66	124	58	125	63	92
Shorthorn steers 33 months	...	...	77	161	49	138	35	110
Shorthorn heifers 33 months	...	...	53	128	32	138	33	139
Aberdeen Angus steers 22 months	...	...	70	132	66	104	57	116
Aberdeen Angus steers 33 months	...	...	65	186	38	144	52	142
Aberdeen Angus heifers 33 months	...	...	49	129	49	121	57	138
Average	...	...	143		128		123	

(b) COEFFICIENT OF VARIABILITY.								
Breed	Period I		Period II		Period III			
Shorthorn steers 22 months	...	...	8.76	8.97	6.45			
Shorthorn steers 33 months	...	...	8.51	7.52	6.01			
Shorthorn heifers 33 months	...	...	7.56	8.47	8.18			
Aberdeen Angus steers 22 months	...	...	9.71	7.64	8.88			
Aberdeen Angus steers 33 months	...	...	10.53	7.92	8.02			
Aberdeen Angus heifers 33 months	...	...	8.03	7.52	8.75			
Average	...	...	8.85	8.01	7.63			

<sup>1</sup> Robertson. *American Journ. Physiol.*, 41, No. 5, 1916.

<sup>2</sup> King. *Anat. Rec.*, No. 10, 1915.

Probably as a consequence of selection and possibly inbreeding, variability has on the whole shown a decrease since 1893. Table XV111 shows the coefficients of variability and standard deviations of steers of 22 and 33 months old, and heifers of 33 months old, of the Shorthorn and Aberdeen Angus breeds for the three periods:—I 1893–1899, II 1900–1906 and III 1907–1913. It will be seen that variability has on the whole decreased during that period.

In addition to the variation in live weight there is also great individual variation in the proportional development of cattle within the limits of any one breed. It has been shown by Henseler<sup>1</sup> that the influence of feeding affects the proportional development considerably, and Waters<sup>2</sup> has shown that the body conformation of steers is considerably affected by the state of nutrition; scanty feeding, while not materially hindering the growth in height, causes retardation of the development of the middle and width of the body. Laurer<sup>3</sup> also found that external circumstances such as highland or lowland conditions influenced the size of the neck in cattle. In horses von Lützow<sup>4</sup> found that the proportions of heart and lungs vary in the different types and Hatai<sup>5</sup> found that exercise has a great influence on the growth of organs in the rat; the heart, liver, and kidneys being 20 % larger in those having exercise. The influence of exercise on the proportions of stock shown in the carcass competitions is well known.

The variation in proportional development in three of the best represented breeds has been calculated and is shown in Table XIX.

Although some parts of the body, such as carcass weight and head, are much less variable than live weight, others are very much more variable. It would naturally be expected that there would be considerable variation in the case of suet and gut fat as well as the other characters which are related to the stage of fattening attained. This was demonstrated for the proportion of carcass by Lawes and Gilbert<sup>6</sup> but the detailed changes in the proportions of the various organs of the body that take place in the process of fattening are still unknown.

The proportions of tripe and intestine are remarkable for the amount of variation which exists. This variation is not only due to the amount of food remaining in the stomach and intestines but is possibly caused

<sup>1</sup> Henseler. *Kühn-Archiv*, Band v, 1914.

<sup>2</sup> Waters. *Proc. Soc. Prom. Agric. Sci.*, 1908.

<sup>3</sup> Laurer. *Deut. Landw. Tierzucht*, No. 50, 1913.

<sup>4</sup> von Lützow. *Landw. Jahrb.*, No. 5, 1908.

<sup>5</sup> Hatai. *Anal. Rec.*, No. 8, 1915.

<sup>6</sup> Lawes and Gilbert. *Journ. Roy. Agri. Soc.*, Vol. 21, 1896.



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by differences in the methods of feeding. Magnan<sup>1</sup> found that the size of the digestive organs in birds was materially altered by the type of food eaten.

Table XIX. *Variation in proportional development of cattle.*

(a) STANDARD DEVIATION. Percentage of live weight.												
Steers of 22 months.												
Breed	No.	Carcass	Suet fat	Cut fat	Tongue	Head	Heart	Tripe	Hide	Blood	Intestine	Uterus
Galloway	...	—	—	—	—	—	—	—	—	—	—	—
Aberdeen Angus	30	2.17	0.33	0.66	0.08	0.34	0.27	1.38	0.63	0.36	0.36	1.51
Welsh	...	—	—	—	—	—	—	—	—	—	—	—
Average	...	1	2.17	0.33	0.66	0.08	0.34	0.27	1.38	0.36	0.36	1.51
Steers of 33 months.												
Galloway	...	28	2.68	0.37	0.66	0.07	0.25	0.35	0.89	0.57	0.31	0.23
Aberdeen Angus	16	2.34	0.28	0.89	0.09	0.24	0.39	1.63	0.65	0.55	0.24	1.85
Welsh	...	31	2.67	0.28	0.54	0.07	0.25	0.22	1.07	0.71	0.25	0.35
Average	...	3	2.36	0.31	0.70	0.08	0.25	0.32	1.20	0.64	0.37	0.27
(b) COEFFICIENT OF VARIABILITY.												
Steers of 22 months.												
Galloway	...	—	—	—	—	—	—	—	—	—	—	—
Aberdeen Angus	30	3.38	27.44	28.74	10.25	8.23	9.83	17.25	9.74	14.26	26.98	17.48
Welsh	...	—	—	—	—	—	—	—	—	—	—	—
Average	...	1	3.38	27.44	28.74	10.25	8.23	9.83	17.25	9.74	14.26	26.98
Steers of 33 months.												
Galloway	...	28	4.14	23.40	21.68	9.35	6.29	13.92	11.63	8.79	12.91	17.12
Aberdeen Angus	16	3.59	20.82	35.18	11.58	6.32	15.35	21.47	11.24	26.83	19.28	20.0
Welsh	...	31	4.16	16.85	17.10	10.24	6.40	8.31	14.42	10.23	11.96	29.01
Average	...	3	3.97	20.36	24.65	10.39	6.34	12.52	15.84	10.09	17.23	21.80

The proportion of blood too shows a large variation, but as only a small number of weighings were made of this tissue not much reliance can be placed on the figures.

The small amount of variation in head depends probably on the attention which this organ has received in selection. It is one of the parts of the animal which is noticeable and so has been standardised by the various Breed Societies.

The "amount unaccounted for" is necessarily a very variable character for it includes the watery stomach and intestinal contents as well as the loss of water from the carcass by evaporation which varies with the fatness of the animal.

<sup>1</sup> Magnan. *Ann. Sci. Nat. Zool.*, Nos. 2-6, 1914.

On the whole more variation exists in the proportions of the body than in the total weight attained by the body and this is probably to be expected as hitherto breeders have not as a rule selected directly for these qualities. A study of the figures given in Table XIX will show that there is ample room for improvements to be effected by selection within any one breed without recourse to crossing.

A point of considerable interest is that while the variability of live weight and that of most organs and tissues increases with age the proportions of suet and gut fat, head, tripe, and intestines appear to be more variable at 22 months than at 33 months of age. The amount of variability present in suet and gut fat at 22 months old should encourage those who are selecting for an animal which will fatten readily at an early age. That tripe and intestines are more variable at the younger ages is in accordance with the known effect of bulky forage as compared with concentrated foods on the development of the rumen in young cattle.

#### *Correlation.*

Reference has been made above to the fact that certain organs tend to vary in weight together and also that a variation in one direction in one organ is often correlated with a counter variation in another organ.

Numerous attempts have been made to correlate different parts of the body by measurement and to correlate anatomical measurements with production but very little has been done to establish the correlation between different parts of the body by weight.

Lawes and Gilbert<sup>1</sup> associated a high percentage of carcass on slaughter with a high fat percentage. Mackenzie and Marshall<sup>2</sup> found however that while generally speaking a high carcass percentage is correlated with high fat content and with a low percentage of cartilage, bone and lean meat, yet there were many and marked individual variations from this rule.

Müller, Max and Narabe<sup>3</sup> found that a negative correlation existed between the thickness of bone and size of the horn in Ayrshire cattle and this has been confirmed for cows of the Kehlheim breed by Laurer<sup>4</sup>.

Smith<sup>5</sup> states that steers with large middle girths made the most

<sup>1</sup> Lawes and Gilbert. *Journ. Roy. Agri. Soc.*, No. 21, 1860.

<sup>2</sup> Mackenzie and Marshall. *Journ. Bd. of Agric. and Fisheries*, 25, No. 6, 1918.

<sup>3</sup> Müller, Max and Narabe. *Landwirtsch. Jahrb.* 46, 1914.

<sup>4</sup> Laurer. *Deut. Landw. Tierzucht*, No. 11, 1910.

<sup>5</sup> Smith. *Nebraska Sta. Bul.*, No. 116, 1910.

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Table XX. *Correlation between different parts of the body in cattle.*

Percentage of live weight.												
I. Grouped by Live Weight:												
% of tissue grouped by	No.	Carcass	Suet fat	Gut fat	Tongue	Head	Heart	Tripe	Hide	Blood	In- testine	Unaccounted for
Highest ...	34	64.29	1.48	3.08	0.87	3.84	2.46	7.59	6.36	[2.27]	1.40	8.77
Average ...	37	64.42	1.44	2.65	0.80	3.99	2.57	7.50	6.68	[2.16]	1.34	8.73
Lowest ...	34	63.76	1.46	2.50	0.86	4.17	2.78	8.11	6.78	[2.22]	1.36	7.76
II. Grouped by Carcase:												
Highest ...	34	—	1.51	2.83	0.81	3.89	2.52	6.98	6.28	[2.26]	1.29	7.39
Average ...	37	—	1.47	2.81	0.81	3.96	2.62	7.77	6.65	[2.20]	1.38	7.95
Lowest ...	34	—	1.42	2.49	0.82	4.14	2.71	8.45	6.79	[2.26]	1.40	10.22
III. Grouped by Suet Fat:												
Highest ...	34	64.38	—	3.02	0.81	4.00	2.59	7.35	6.40	[2.31]	1.38	7.88
Average ...	37	64.15	—	2.86	0.83	3.97	2.57	7.70	6.47	[2.21]	1.43	8.54
Lowest ...	34	63.36	—	2.39	0.80	4.04	2.66	8.11	6.72	[2.18]	1.24	9.24
IV. Grouped by Gut Fat:												
Highest ...	34	64.55	1.65	—	0.80	3.84	2.38	7.15	6.50	[2.29]	1.44	8.29
Average ...	37	64.24	1.36	—	0.80	4.00	2.99	7.41	6.68	[2.23]	1.35	8.54
Lowest ...	34	63.94	1.42	—	0.83	4.15	2.70	8.45	6.78	[2.02]	1.28	8.71
V. Grouped by Tongue:												
Highest ...	34	63.74	1.46	2.51	—	4.09	2.73	7.94	6.77	[2.19]	1.38	8.49
Average ...	37	64.43	1.53	3.02	—	3.90	2.53	7.57	6.39	[2.23]	1.49	9.03
Lowest ...	34	64.28	1.40	2.71	—	3.97	2.56	7.67	6.56	[2.31]	1.30	8.81
VI. Grouped by Head:												
Highest ...	34	62.91	1.41	2.39	0.83	—	2.78	8.26	7.05	[2.28]	1.35	8.71
Average ...	37	64.69	1.48	2.67	0.80	—	2.57	7.47	6.54	[2.17]	1.31	8.39
Lowest ...	34	64.83	1.50	3.22	0.80	—	2.46	7.47	6.12	[2.21]	1.40	8.47
VII. Grouped by Heart:												
Highest ...	34	63.74	1.43	2.51	0.81	4.07	—	7.88	6.71	[2.24]	1.41	8.49
Average ...	37	64.16	1.43	2.64	0.81	4.02	—	7.84	6.56	[2.29]	1.31	8.68
Lowest ...	34	64.58	1.54	3.13	0.80	3.88	—	7.44	6.79	[2.25]	1.34	8.51
VIII. Grouped by Tripe:												
Highest ...	34	62.97	1.38	2.49	0.83	4.05	2.63	—	6.64	[2.20]	1.35	8.69
Average ...	37	64.30	1.48	2.71	0.80	4.00	2.62	—	6.65	[2.12]	1.34	8.54
Lowest ...	34	65.20	1.53	3.02	0.80	3.93	2.50	—	6.42	[2.22]	1.38	8.65
IX. Grouped by Hide:												
Highest ...	34	63.24	1.38	2.41	0.83	4.15	2.69	8.08	—	[2.22]	1.30	8.64
Average ...	37	64.29	1.48	2.68	0.80	4.02	2.64	7.60	—	[2.05]	1.35	8.59
Lowest ...	34	64.04	1.53	3.18	0.80	3.81	2.48	7.90	—	[2.35]	1.39	8.50
X. Grouped by Blood:												
Highest ...	13	63.20	1.32	3.10	0.80	3.90	2.41	7.93	6.27	—	1.29	9.88
Average ...	15	64.45	1.49	3.29	0.83	3.86	2.48	7.38	6.18	—	1.38	8.65
Lowest ...	13	64.36	1.36	2.71	0.82	3.85	2.46	7.94	6.40	—	1.27	9.27
XI. Grouped by Intestines:												
Highest ...	34	63.13	1.56	2.99	0.81	4.00	2.62	7.48	6.58	[2.17]	—	9.22
Average ...	37	64.57	1.42	2.60	0.81	3.80	2.62	7.89	6.58	[2.14]	—	8.11
Lowest ...	34	64.74	1.43	2.68	0.81	4.00	2.51	7.78	6.56	[2.22]	—	8.37
XII. Grouped by "Unaccounted for":												
Highest ...	34	62.26	1.41	2.76	0.82	4.04	2.61	7.79	6.82	[2.28]	1.43	—
Average ...	37	64.58	1.43	2.74	0.80	3.92	2.61	7.82	6.48	[2.02]	1.33	—

gains when fattening and that the rate of gain when fattening was not associated with size of bone and only slightly with heart girth.

The material available in the present paper has been tabulated to obtain evidence of any correlation which existed. The methods used have been explained under the description of Table XX above and the results obtained are shown in this table. The results have been judged to show correlation only if they run consecutively throughout the series—Highest, Average, Lowest.

The conclusions arrived at are in some cases rather unreliable owing to the small numbers of animals available but can be checked to some extent by the reciprocal groupings; thus animals with the highest amount of suet fat show the largest amount of carcass and also those with the highest amount of carcass show the largest amount of suet fat.

The following tentative conclusions are indicated:—

*The live weight* is directly correlated with the proportion of gut fat and also “unaccounted for” as well as inversely with the percentage of head, heart and hide; that is, the smaller the live weight the larger is the proportion of head, heart and hide. As the bulk of the head (with legs) is mainly bone, it may be inferred that high live weight is correlated inversely with the proportions of the skeleton. This supports Tridon’s<sup>1</sup> finding that the heaviest calves had the least percentage of bone and that the percentage of bone in legs of beef decreased with increase in weight of the animal.

*The proportion of carcass weight* is directly correlated with the proportion of suet and gut fat and inversely with the proportion of head, heart, tripe, intestines and “unaccounted for.” When different breeds are compared however (see under Breed above, Table C) it will be seen that there is no correlation between fat percentage and carcass percentage. Within the limits of a breed there is correlation between these two parts but outside the breed this correlation does not hold. This supports Marshall and Mackenzie’s conclusions quoted above. Tomhave<sup>2</sup> found that the fatter an animal the higher is its yield of carcass although Hall and Emmett<sup>3</sup> found that a high percentage of carcass is not always attended by a large amount of internal fat.

*The proportion of suet fat* is directly correlated with the percentage of carcass, gut fat and blood; the correlation with the last two however is not confirmed by the reciprocal groupings. Suet fat is also correlated

<sup>1</sup> Tridon. *L’Hygiène d. l. Viande et d. Lait*, Year 8, No. 1, 1914.

<sup>2</sup> Tomhave. *The Country Gentleman*, Vol. 80, No. 32, 1915.

<sup>3</sup> Hall and Emmett. *Illinois Sta. Bul.* No. 158, 1912.

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inversely with the proportion of tripe, hide and "unaccounted for." The relation between high fat and low "unaccounted for" is probably due to the fact that a fat carcass loses less water by evaporation than a thin one. Magnan<sup>1</sup>, who studied the relative weight of fat to weight of the body in different species of animals, found that herbivorous animals had the smallest proportion of fat while omnivorous animals had the largest.

*The proportion of gut fat* is directly associated with the proportion of carcass, blood and intestine; the two latter however are not confirmed by the reciprocal groupings. The proportion of gut fat is also associated inversely with the proportion of head, tripe, hide and "unaccounted for"; the latter however is not confirmed by the reciprocal grouping.

*The proportion of tongue* is correlated only with the proportion of blood but this is not confirmed by the reciprocal grouping.

*The proportion of head* is directly correlated with the proportion of heart, hide and "unaccounted for"; the latter however is not confirmed by the reciprocal grouping. The proportion of head is also associated inversely with the proportion of carcass, gut and suet fat although the latter is not confirmed by the reciprocal grouping. As head (including legs) consists largely of bone it may be inferred that large-boned animals have usually a large proportion of hide but a small proportion of carcass.

*The proportion of heart* is directly correlated with the proportion of head and tripe and inversely with the proportion of carcass and gut fat.

*The proportion of tripe* is directly correlated with the proportion of head and heart and inversely with the proportion of carcass, suet and gut fat.

*The proportion of hide* is directly associated with the proportion of head, heart, tripe and "unaccounted for," although these, with the exception of the first-named, are not confirmed by the reciprocal groupings.

The proportion of hide is also correlated inversely with the proportion of carcass, suet fat, gut fat and intestines, the latter however is not confirmed by the reciprocal grouping.

*The proportion of blood* is directly associated with a high proportion of head, this however is not confirmed by the reciprocal grouping. Only a small number of blood weighings are given so that it is difficult to make comparisons with this tissue.

*The proportion of intestine* is directly correlated with the proportion of carcass.

*The proportion of "unaccounted for"* is inversely correlated with the

<sup>1</sup> Magnan. *Compt. Rend. Soc. d. Biol.*, Vol. 73, No. 33, 1912.

proportion of carcase and suet fat. This confirms the work of Tomhave<sup>1</sup> who found that a thin carcase loses more weight than a well-finished one, owing to the greater evaporation of water. The proportion of "unaccounted for" is also associated with the proportion of intestine but this is not confirmed by the reciprocal grouping.

It would appear that, on the whole, the proportions of carcase, suet and gut fat vary together in the same way and also that the proportions of head, heart, tripe, hide and possibly "unaccounted for" also vary together in the same way and generally in opposition to those of the first group.

#### *Selection.*

In order to study the progress made by selection since 1893, the weights of the animals exhibited have been grouped in seven year periods: Period I extending from 1893-1899 inclusive, Period II from 1900-1906 inclusive, and Period III from 1907-1913 inclusive.

It was hoped also that the examination of the records would reveal the general tendency of the period as regards size, and would show the effect of the Breed Society standards in encouraging increased or decreased size. It has been stated, but without proof, that the modern system of cake feeding tends to more "quality" and smaller size than the old system of feeding exclusively with bulky home grown foods.

During the 21 years over which the records exist the general tendency has been on the whole to increase in weight; this can be seen in Table I and also more clearly in Table XXI in which all breeds have been calculated to a common age.

The Sussex and perhaps the Galloway are the only breeds which show a consistent decrease in weight. Devons and Red Polls on the other hand show a fairly consistent increase in weight, while the tendency with the Hereford seems to be increase in weight in the male but decrease in the female (i.e. the secondary sexual characters intensified, see "Sex" above).

The Dexter breed has decreased in weight in Period II and increased again in Period III by an approximately equal amount. Shorthorn and Welsh cattle have varied in the same way.

On the whole the small breeds have increased in size while the larger breeds have remained stationary or have decreased in size, presumably in the attempt to obtain more "quality."

<sup>1</sup> Tomhave. *The Country Gentleman*, Vol. 80, No. 32, 1915.

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Table XXI. *Progress of cattle by weight (lbs.) from 1893 to 1913.*

Period I—1893-1899, Period II—1900-1906, Period III—1907-1913.

Breed	<i>Steers.</i>								
	22 months						33 months		
	Period I		Period II		Period III		Period I		Period II
	No.	Weight	No.	Weight	No.	Weight	No.	Weight	No. Weight
Devon ... ..	58	1177	56	1196	52	1272	83	1506	48 1570 55 1612
Hereford ... ..	61	1350	46	1308	43	1445	46	1795	35 1892 33 1810
Shorthorn ... ..	66	1415	58	1393	63	1425	77	1892	49 1834 35 1811
Sussex ... ..	53	1390	62	1398	74	1381	56	1823	54 1786 55 1710
Red Poll ... ..	13	1228	25	1241	27	1320	32	1564	28 1967 17 1812
Aberdeen Angus ... ..	70	1359	66	1382	57	1384	65	1766	38 1818 52 1717
Galloway ... ..	31	1222	35	1235	32	1212	47	1617	38 1595 35 1511
Welsh... ..	27	1369	56	1357	52	1373	63	1753	74 1662 91 1619
Dexter ... ..	14	864	44	771	29	857	31	1040	43 1007 25 1010
Shorthorn x Aberdeen Angus	17	1400	15	1380	25	1392	10	1880	13 1821 19 1818
Aberdeen Angus x Shorthorn	16	1396	20	1457	13	1422	18	1729	16 1857 12 1810
Average all breeds ... ..	11	1288	11	1290	11	1316	11	1670	11 1683 11 1610
<i>Heifers.</i>									
Devon ... ..	—	—	—	—	—	—	23	1356	23 1415 25 1410
Hereford ... ..	7	1327	4	1221	9	1265	20	1632	13 1585 20 1510
Shorthorn ... ..	2	1260	3	1268	6	1315	53	1694	32 1665 33 1610
Sussex ... ..	—	—	—	—	—	—	25	1639	44 1690 32 1610
Red Poll ... ..	—	—	—	—	—	—	12	1544	24 1484 21 1410
Aberdeen Angus ... ..	—	—	—	—	—	—	49	1607	49 1608 57 1610
Galloway ... ..	—	—	—	—	—	—	24	1398	30 1315 25 1310
Welsh ... ..	—	—	—	—	—	—	21	1464	31 1513 44 1510
Dexter ... ..	3	852	9	775	1	821	21	966	26 866 18 810
Shorthorn x Aberdeen Angus	7	1267	15	1335	21	1299	7	1783	8 1725 15 1710
Aberdeen Angus x Shorthorn	5	1321	14	1333	13	1319	16	1599	17 1569 11 1510
Average all breeds ... ..	5	1205	5	1186	5	1203	11	1516	11 1497 11 1410

The general tendency to increase in weight is more marked at 22 than at 33 months which is in accordance with the commonly accepted view that the modern tendency is towards more early maturity.

Going further back still to the weights of cattle shown at Smithfield in 1840-42<sup>1</sup> it will be seen (Table XXII) that the carcase weights of Shorthorns and Aberdeen Angus steers were larger than those of the present day, and also that they contained in 1840-43 very much more fat than the present day carcases. The latter fact is probably an explanation of the apparent decrease in weight for, if the carcase weights of cattle shown in the live classes in 1893-1913 (calculated at 64 per cent.)

<sup>1</sup> *The Farmer's Magazine*, London, 1840, 1841 and 1842.

carcase) are compared with the carcase weights of 1840-42, it will be seen that there is a slight increase in size since that time. The cattle exhibited in the "live" classes of to-day are probably shown in the same "condition" as those exhibited in the "carcase" classes of 1840-42 and the modern "carcase" class animal is probably not so heavily fattened. While this holds good with the Shorthorn and Aberdeen Angus breeds, Table XXII shows that in the carcase classes, despite the less fat "condition" of the animals exhibited now-a-days, the Herefords and Devons have increased in size considerably since 1840-42. Comparison with the "live" classes of 1893-1913 still further confirms this statement.

Table XXII. *Comparative carcase weights of cattle of 33 months old in Periods 1840-1842 and 1893-1913.*

Breed	Period	Class	No.	Steers	
				Carcase lbs.	Loose fat lbs.
Shorthorns or Durhams ... ..	1840-1842	Carcase	14	1163	150
" " ... ..	1893-1913	Carcase	4	1096	79
" " ... ..	1893-1913	Live*	161	1190	—
Herefords ... ..	1840-1842	Carcase	10	939	140
" ... ..	1893-1913	Carcase	1	999	83
" ... ..	1893-1913	Live*	114	1181	—
Devons ... ..	1840-1842	Carcase	2	825	107
" ... ..	1893-1913	Carcase	3	938	68
" ... ..	1893-1913	Live*	186	1001	—
Aberdeen Angus or Aberdeenshire	1840-1842	Carcase	1	1056	—
" " "	1893-1913	Carcase	16	985	58
" " "	1893-1913	Live*	155	1135	—

\* Calculated as 64% of live weight.

Table XXIII shows, for a few breeds (of which sufficient examples have been obtained to give definite figures), the way in which the proportions of the body have varied during the period under consideration.

The average of the three breeds shows that, both at 22 and 33 months old, the percentage of the carcase to live weight has fallen in Period II and risen again in Period III. Both suet and gut fat show the same changes but the rise of gut fat in Period III does not balance the fall in Period II. The proportion of tongue remains practically constant throughout. The proportion of head rises in steers of 22 months of age in Period II but falls in Period III, although at 33 months it continues to increase in proportion throughout. The proportion of heart (with



Table XXIII. *Proportions of organs (as percentage of live weight) in cattle slaughtered between 1893 and 1913.*

Breed	Sex	Age mths	Period No.	Period I—1893-1899,					Period II—1900-1906,					Period III—1907-1913,					In- cluded for	Un- counted
				Carcass weight	Suet fat	Gut fat	Tongue	Head	Heart	Tripes	Hide	Blood	Testes							
Aberdeen Angus, Welsh and Galloway	Steers	22	I	16	63.87	1.31	2.93	0.79	4.08	2.65	7.81	6.72	[2.40]	1.42	8.42					
			II	16	63.36	1.17	2.34	0.82	4.31	2.71	7.85	6.65	[2.40]	1.30	9.19					
			III	28	64.68	1.33	2.37	0.79	4.14	2.80	7.78	6.82	[2.42]	1.30	7.99					
	33	I	25	64.68	1.57	3.23	0.81	3.78	2.36	7.51	5.91	[2.14]	1.33	8.82						
			II	22	64.47	1.34	2.78	0.79	3.94	2.66	7.63	6.42	[2.18]	1.33	8.64					
			III	28	64.67	1.73	2.81	0.79	4.02	2.64	7.46	7.02	[2.36]	1.46	7.40					

the exception of a slight fall in Period II at 33 months old) shows an increase. Tripe at both ages rises in Period II but falls again below the original level in Period III; hide follows the same course, but at 33 months there is a rise throughout the whole period. Blood remains the same in Periods I and II but shows an increase in Period III. The proportions of intestine remain practically the same throughout. The amount "unaccounted for" at 22 months of age increases in Period II and decreases again in Period III, falling below its original level; in steers of 33 months it shows a steady decrease.

Considered generally the proportions of carcase weight, suet fat and gut fat have decreased in Period II but have increased again in Period III, while the proportions of head, heart, tripe and "unaccounted for" have increased in Period II but have decreased again in Period III. In Period II, 1900-1906, there seems to have been a falling off in "quality" which has improved again in Period III, 1907-1913.

#### *Season.*

In order to determine the effect of season three well-represented breeds have been selected and the records of each year's exhibits have been averaged separately, after correcting for age; and the difference between this average and the mean of the breed as shown in Table II has been calculated. This plus or minus balance for each year is shown in Table XXIV for each breed separately; the total for all three breeds of each age and also for the total of cattle of both ages has also been given. In this way the fluctuations in weight due to season are easily seen, although it should be remembered that the variations due to "Selection" (see above) have not been eliminated.

The results show that there is seasonal variation, the difference between 1906 and 1907 being very marked; but whether the variation is due to the large individual variation in the breeds or is due to seasonal conditions it is difficult to determine.

The causes of this variation are not easy to find as the cattle exhibited come from widely different districts of the British Isles and are fed under various conditions. In the last three columns of Table XXIV the annual plus or minus balance above or below (1) the average rainfall for England and Wales, (2) the average root crop for England and (3) the average hay crop for England during the period 1893-1913 has been given. It will be seen that there is no evidence of correlation between any of these and the weights of the animals shown and it is hardly to be expected as animals fed for shows would be fed regardless of these conditions.

288 *Relative Growth and Development of Cattle*Table XXIV. *Effect of season on rate of growth in cattle (steers).*

Year	Welsh		Shorthorn		Aberdeen Angus		All breeds		All breeds all ages	Rainfall inches	Root crops tons per acre	Hay crops tons per acre
	22 mths	33 mths	22 mths	33 mths	22 mths	33 mths	22 mths	33 mths				
1893	—	+108	+6	-25	-95	-76	-89	+7	-82	-4.98	-3.19	-11.94
1894	—	+70	+28	+47	-2	-17	+26	+100	+126	+2.95	+0.44	-4.3
1895	—	+100	+27	+105	+34	-52	+61	+153	+214	-1.88	-1.24	-2.42
1896	—	+94	-3	+75	-22	+85	-25	+254	+229	-2.25	-2.57	-5.48
1897	-20	+8	-31	+59	+12	+42	-39	+100	+70	+0.95	+0.42	-1.64
1898	+4	+73	+46	-6	-13	+22	+37	+89	+126	-3.77	-1.47	-5.8
1899	+24	+77	+83	-6	+68	-31	+175	+40	+215	-1.67	-2.24	-0.7
1900	+18	-52	-12	-7	+132	+57	+138	-2	+136	+3.18	+1.44	-0.92
1901	+66	+105	+42	-15	-25	+121	+83	+211	+294	-3.36	-0.41	-3.48
1902	+42	-37	+33	+30	+27	+106	+102	+99	+201	-5.18	+2.32	-4.2
1903	-73	-87	-81	-2	+65	+16	-89	-73	-162	+10.62	-0.61	+3.04
1904	-4	+54	-30	-95	-17	+91	-81	+50	-31	+2.94	+1.03	-1.4
1905	-27	-7	+3	-25	-55	-70	-79	-102	-181	-4.39	+4.33	-0.9
1906	-66	-132	-30	-37	+40	+43	-56	-126	-182	+1.04	+0.82	-0.4
1907	37	+39	+10	-23	+63	+85	+36	+101	+137	+0.42	+1.29	-4.5
1908	+4	+39	+10	-18	-5	-9	+9	+12	+21	-2.54	+1.83	+2.04
1909	0	+12	-54	-26	+28	-62	-26	-76	-102	+2.11	+2.73	-0.2
1910	+46	-70	-35	-54	+107	+73	+118	-51	+67	+5.34	+2.76	-2.5
1911	+29	-25	+11	-156	-9	-28	+31	-209	-178	-0.59	-2.98	-4.4
1912	+6	+10	+40	+64	+6	+4	+52	+78	+130	+8.66	-0.59	-0.3
1913	-39	-37	+42	+22	-47	-31	-44	-46	-90	+1.09	-0.50	+2.3

Boetticher<sup>1</sup> has shown however that there is a correlation between the climate and body weight of warm-blooded animals and Sumner<sup>2</sup> has found that such a correlation between temperature and growth exists in mice. Watson and Hunter<sup>3</sup> have found that an unsuitable diet if used in the growing period caused a permanent stunting of growth.

Possibly a comparison of the seasonal differences with the climate during certain months of the year, particularly those months which control the quality of the grass and root crops, might show some relationship. Undoubtedly the quality of the hay and root crops would affect the average fattening steer very much more than those exhibited at Smithfield owing to the large part which concentrated food plays in the rations of the latter.

If a comparison is made in column five of Table XXIV between the differences at 22 months and 33 months it will be seen that plus and minus signs occur together in the same year seven times whereas two plus

<sup>1</sup> Boetticher. *Zool. Anzeiger*, Vol. 44, 1913.<sup>2</sup> Sumner. *Journ. Exp. Zool.*, No. 3, 1913.<sup>3</sup> Watson and Hunter. *Proc. Phys. Soc., Journ. of Physiol.*, Nos. 4-5, 1905.

signs or two minus signs occur 14 times. This seems to indicate that the seasonal variation is not a chance one and the conclusion must be arrived at that there is seasonal variation but that its causes cannot at present be determined.

In conclusion attention should be drawn to the small numbers of individuals on which conclusions have often been based and it is desired to impress upon those who read these conclusions that the results are to be considered as tentative only. It is hoped that others, who may be able to obtain data concerning a larger number of animals, may be able to confirm or contradict the conclusions expressed in this paper.

My thanks are due to Mr G. Udny Yule for the advice he has given me in the preparation of this paper. I am also indebted to Mr W. P. Crosland for his criticism and to Mr E. J. Powell who has supplied me with catalogues of the Smithfield Show for the period under consideration.

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## THE PROTEIN CONTENT OF WHEAT GROWN WITH IRRIGATION.

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WITH the development of irrigation projects in intermountain areas of the Rocky Mountain States has come an enormous increase in the amount of wheat produced annually with irrigation. The crop commands the attention and consideration of millers and grain men generally in intermountain sections and will continue to do so because there is in cultivation at present a small fraction only of the acreage that can be successfully farmed with irrigation. The general run of irrigated wheat regardless of the class to which the varieties may belong is plump and relatively heavy. It is unfortunately at the same time soft and starchy and because of its relatively low protein content is almost invariably sold on markets that do not stress strength in wheat flour. The irrigation farmer has no particular reason for dissatisfaction with the money return for his crop; yields are good and the demand for wheat so great that any and all grades are quickly absorbed by home and foreign markets. The United States Grain Standards Act, however, makes it plain to him that an equal number of bushels of hard wheat, or of wheat substantially richer in protein, would net him yearly a handsome sum over that which he now receives. Wheat is so generally fundamental in the human diet, that, economically speaking, quality of grain for milling purposes is a matter of national importance, the richer our wheats in protein the greater their value as food, and, in times of shortage, the greater can be the dilution of flours made from them in the making of light bread. Perhaps no other food stuff varies so widely in its content of protein because of favourable or unfavourable conditions of growth for its elaboration. There is unfortunately in the minds of wheat growers and millers generally the notion that irrigation and pronounced starchiness of kernel are inseparably linked. The unreasonableness of that view, the scarcity of evidence in support of it, and the

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growing importance of irrigated wheats in this State suggested as far back as 1908 the present investigation. It now seems certain that there is nothing fundamentally incompatible with irrigation, as it may be practised in southern Idaho at least, and the notion always held by a few that wheats of high protein content are possible with it, and under conditions of growth, too, that make for maximum yields.

Incidentally this investigation contributes very substantially to a better understanding of the factors which control in protein elaboration by the wheat plant under any conditions of growth.

#### THE LITERATURE REVIEWED.

The literature is not particularly rich in reports of investigations which sought to establish relationships between irrigation practice and the composition of plant parts. It is much richer in reports of investigations and observations which bear somewhat indirectly upon the questions involved. Many investigators, for example, have attached great importance to the influence of certain factors of climate, as rainfall, humidity, sunshine and temperature, upon the elaboration of protein by the wheat plant and are very positive in their conclusions that the environment imposed by climate determines between wheat-growing sections the relative richness of their wheats in protein. In our judgment a great deal of the evidence submitted in support of this view is based far too largely upon general observations and is for that reason not convincing. The extensive development of semi-arid lands within recent years and their splendid adaptability under irrigation to the growth of the small grains make all questions relative to quality of grain important economic ones in the intermountain states. We have assumed that it would serve no useful purpose in this connection to review any other than the more recent investigations.

Widtsoe<sup>(4)</sup> in 1901 grew a variety of wheat called New Zealand in Cache Valley, Utah, with varying amounts of irrigation water ranging from 4.63 to 40 inches. The soil used is a shallow one, varying in depth between 9 and 59 inches. It is underlaid with coarse gravel to a depth of 300 feet. Widtsoe noted differences in the protein content of the harvested wheat kernels ranging from 26.72 % to 15.26 % and, notwithstanding pronounced irregularities, attributed these differences to variations in amounts of water applied. With increase of water there was a decrease in the protein content of the harvested grain.

Humphries<sup>(5)</sup> cites the fact that the 1903 season in England was one of abnormal rainfall and sunshine and that the season of 1904 was

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much drier with more than the usual amount of sunshine. He states that the 1903 crop of English wheat was fully as good if not better than that of 1904 for flour-making purposes. He does not cite any analytical data in support of his observations. He rejects the notion that rainfall is a determining factor in determining quality in milling wheat, pointing out the fact that the rainfall at St Paul, Minnesota, during the growing months is greater than it is in England, and still the Minnesota-grown wheat is generally recognized as far superior to the English-grown wheat.

LeClerc(9) reports the growth of Kubanka in 1904 in seven localities with 15 inches or less of rainfall and in six localities with more than 15 inches of rainfall, or with irrigation. He found by analysis a difference of .47 % of nitrogen in favour of the wheat grown in the drier regions. He notes also a difference of 3.3 % in the average protein content of seven samples from irrigated sections when compared with seven samples of the same variety grown in as many different localities in the western states without irrigation. The non-irrigated samples were richer in protein. A still greater difference was noted by him when irrigated and non-irrigated Durum wheats grown in Mexico were compared. Again LeClerc found that between samples of Kubanka wheat grown in Idaho and Colorado, with and without irrigation, there was an average difference of .73 % of nitrogen in favour of the dry-farmed samples.

Shutt(11) concluded from his work with Red Fife and Kharkof grown at Lethbridge, Alberta, in 1908 on dry-farmed and irrigated land that irrigation lowers the protein content. From this work and earlier determinations of protein in wheat grown on new and old lands, Shutt reached the conclusion that soil moisture is a factor of great importance in determining the protein content of wheat.

In 1908 Jones and Nelson(6) of the Idaho Experiment Station grew on the Caldwell Substation in the Snake River valley of southern Idaho, Palouse Bluestem and Little Club each in seven plats with varying amounts of irrigation water ranging by differences of 3 inches and 6 inches from no inches to 24 inches. The rainfall in that section of the State is practically negligible for crop-growing purposes. The badly shrunk samples from the plats to which no water had been given in all cases but one were highest in protein. The analytical data on all *normally* matured samples furnish inconclusive evidence on the influence of irrigation water on the storage of protein in the wheat kernel. In no instance did the application of least water produce wheat of the highest protein content. The work was repeated in 1909. The high

percentages of protein for the normally matured samples of both varieties that year are worthy of special comment as indicative of the possibilities of high-protein wheat on irrigated lands.

Shaw<sup>(10)</sup> conducted experiments with six different types of wheat on the University Farm at Davis, California, during the season of 1908-9. For each type, plat A received no irrigation; plat B received one irrigation just after the plants were out of the boot; and plat C received two irrigations, one as given to plat B and one after the grain was set. The amount of irrigation water applied is not mentioned, neither is the amount of rainfall which, however, we find from Weather Bureau reports to have been 12.36 inches for the time intervening between sowing and harvesting. A part of each plat was cut early, June 24; the other part one week later. From his tabulated and analytical data Shaw concludes that with an increase in irrigation water the protein of wheat is lowered. For the early-cut crop the average percentages of protein for the six types from plats A, B and C were 14.56, 13.11 and 12.77 % respectively (all presumably reduced to the dry basis). For the late-cut crops the corresponding figures are 14.83 %, 14.44 % and 14.04 %.

In very close connection with his work with irrigation, Shaw mentions the fertilization of wheat plats for several years with sodium nitrate and other fertilizers. From his analytical data he concludes that the application of nitrates or other nitrogen-containing fertilizers is without effect in increasing the protein content of wheat.

Stewart and Hirst<sup>(12)</sup> grew ten varieties of wheat on the Greenville farm in Cache Valley, Utah, with the application of no inches, 15 inches and 25 inches of irrigation water. The averages for the protein content of the harvested grain were 15.45, 14.35 and 14.00 % respectively. Corresponding averages for the flours resulting from the grinding of the wheat samples were 13.62, 12.92 and 12.63 %.

Howard<sup>(4)</sup> and his co-workers, from work conducted at several stations in India between 1907 and 1912, at some with irrigation and at others with normal rainfall only, conclude that irrigation and high quality of grain may go together when the cultivation is suitable and the amount of irrigation water regulated.

The Department of Agriculture<sup>1</sup>, New South Wales, reports the exhibition of samples of Bobs, Comeback and Florence wheats at the Royal Agricultural Society's show in Sidney during the years 1912 to 1916 inclusive. The samples were grown in the several wheat-growing

<sup>1</sup> Private correspondence.



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districts of the State with rainfall during the growing season ranging from 4.5 to 15.22 inches. The wheats had their percentages of flour determined and the flours their percentage content of gluten and baking strength. With the analytical data for any variety arranged for correlation with data for rainfall, there does not appear to be for any of the varieties or for any district a direct connection between gluten content and rainfall.

Thatcher(13) in a summary of wheat investigations conducted in Washington from 1906 to 1912 inclusive correlated the rainfall of eastern Washington between 1905 and 1909 with the average content of protein in wheat samples secured during the same years. He reached the conclusion that the protein content of wheat in eastern Washington decreases with increase of rainfall.

Bailey(1) in a similar manner correlated data on the rainfall of the different wheat-growing sections of Minnesota from April to September, 1911, with the average protein content of wheat samples analysed by him as representative of the products of the several sections the same year. His conclusions are that on the whole increased rainfall in Minnesota is accompanied by relatively lowered protein content in the harvested grain.

Harris(2) from his investigations of wheat conducted in pots under greenhouse conditions at Cornell University, states that the kernels from the plants grown in wet soils were soft and starchy. He found the percentage of nitrogen in both straw and grain to be highest in plants grown on the driest soils. With an increase of soil moisture up to 37½ % there was a gradual decrease in the percentage of nitrogen. Harris is careful to state that the grain of highest protein content was plump and apparently of normal maturity. He observed that the protein content of both wheat and straw was influenced by the period of growth at which high or low soil moisture conditions prevailed. Highest protein content was secured with a low soil moisture content up to the booting stage of the plant and a high soil moisture content from then on to maturity. Harris further notes that fertilizers high in nitrogen increased the nitrogen content of his crops.

Jones and Colver(7) from observations in the field and from analytical work performed on samples of dry-farmed and irrigated wheats collected over a term of three years in representative dry-farmed and irrigated sections of southern Idaho conclude that some varieties are more affected by irrigation than others.

Headden(3) in speaking of wheats grown in 1913 and 1914 in Colorado

with one and two acre-feet of irrigation water states that no results were secured that show conclusively that differences in amounts of water used made any difference in weights of wheat per bushel and composition of grain. In 1913 he secured and analysed a large number of samples of Dicklow wheat grown in southern Idaho in 1913 in duty-of-water investigations. The amounts of water used in growing the grain from which Headden secured samples ranged from .66 acre-feet to 3.28 acre-feet. The protein in the samples ranged from 7.18 % to 9.48 %. The sample highest in protein was grown with the next to the least amount of irrigation water. The sample next highest in protein, 9.16 %, was grown with the maximum application of water. The samples next highest in protein, 8.97 % and 8.94 %, were grown with 1.62 acre-feet and 2.34 acre-feet of water respectively. Turkey Red grown the same year in the same line of investigation with .47, .89 and .93 acre-feet of water produced grain containing 10.56, 10.57 and 10.65 % of protein respectively.

In 1914 Headden again secured samples of wheat grown in southern Idaho in duty-of-water investigations. This time the samples were of the Marquis variety, grown on six one-tenth acre plats with 1, 2 and 3 acre-feet of irrigation water with barnyard manure amounting to 15.7 loads per acre, and without manure. The irrigation season for the different plats was between June 2 and July 16 for those given 1 acre-foot, between May 21 and July 15 for those given 2 acre-feet, and between May 11 and July 15 for those given 3 acre-feet of water. The number of irrigations for the 1, 2 and 3 acre-feet applications was 3, 5 and 7 respectively. The grain ripened July 24 and 25, 114 days from the time of planting. Without exception the development of the grain was good in so far as could be determined by weight of kernel. Yields of both straw and grain were increased with the 2 and 3 acre-feet applications and still further increased by the application of manure. The protein percentages of the harvested grain for the unmanured and the manured plats were 10.42 and 10.55, 10.52 and 10.81, and 10.52 and 11.93 from plats given 1, 2 and 3 acre-feet of water respectively. In summation of his work with irrigation, Headden concluded that neither the amount nor the distribution of irrigation water made any material difference in the composition of the grain.

From extensive experimental work and large numbers of analyses, Headden is strongly of the opinion that the soil's content of available nitrogen is the determining factor in the elaboration of protein by the wheat plants.

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Widtsoe and Stewart<sup>(15)</sup> in extensive experiments conducted on the Greenville farm in Cache Valley, Utah, to determine the effects of variations in amounts of irrigation water upon the composition of grains and forage crops grew wheat with as little as 5 and as much as 50 inches of irrigation water in addition to the normal rainfall of 15 inches. From their analytical data they conclude that the protein content of wheat is lowered as the amount of irrigation water is increased.

Jones and Colver<sup>(8)</sup> from work conducted with hard wheats under irrigation on the Gooding and Aberdeen stations in southern Idaho conclude that under conditions which make for rapid nitrification of soil organic matter rich in nitrogen, hard wheats of the very highest quality are possible with irrigation. Some remarkably high percentages of protein are recorded for the years 1914, 1915 and 1916 for Minnesota Bluestem and Glyndon Fife grown with normal irrigation.

From this review of the literature it is perfectly apparent that very divergent views are held by the various investigators in this field regarding the influence of irrigation water upon the composition of wheat.

### EXPERIMENTAL.

The lease of a 40 acre tract of raw sagebrush land in 1909 two miles south of Gooding by the Experiment Station for the conduct of experimental work in the irrigation of farm crops provided splendid opportunities and the necessary facilities for the conduct of this particular piece of work. Most fortunately, too, the conditions under which the work was commenced are essentially identical with those which confront the man who takes up raw land in the semi-arid regions of the intermountain states for conversion into farm land. Moreover the conditions prevailing on the Gooding farm at the close of our experimental work were precisely those which prevail after a similar length of time on the average irrigated farm in southern Idaho whose owner brings to his task of development a keen appreciation of the needs of these lands for enrichment with nitrogen-containing organic matter. The investigation is directly applicable to irrigation practice.

The tract of land on which our experimental work was conducted was known between 1909 and 1917 as the Gooding Substation. It lies at an elevation of approximately 3600 feet in the Snake River valley a little nearer the western than the eastern border of the State. The surface soil is a medium clay loam. It has a fairly heavy clay subsoil and is underlaid at a depth of 10 or 12 feet by the basaltic lava rock that is characteristic of southern Idaho. The farm is fairly represen-

tative of the Snake River plains area on which wheat and other small grains are grown extensively, mostly with irrigation. The average annual rainfall between 1910 and 1916 inclusive was 9.2 inches. From 1911 on, the farm was under the superintendency of Mr John S. Welch to whom credit is due for cordial cooperation in planning and executing the field work. The work was commenced in 1910 and was continued without interruption or serious mishap through 1916. The objective points at the beginning of the investigation were: (1) additional data in support of or against the commonly held opinion that low-protein wheat invariably results from the practice of irrigation, (2) fundamental reasons for the influence of soil water on protein formation, and (3) the determination of cumulative effects on protein content from the application of varying amounts of irrigation water. As will be noted later, our ideas regarding the fundamental problems involved underwent some revision with the progress of the work. Its completion put us in possession of a somewhat different kind of information than we anticipated at the start.

#### PLAN OF WORK.

The plan of work was comparatively simple. It involved (1) the growing of three varieties of wheat side by side in several plats of one-fifth and one-tenth acre each in such manner that varying amounts of irrigation water could be applied from no inches to as much as the soil could be made to absorb conveniently; (2) the quantitative estimation of soil nitrates at frequent intervals in the plats of one series to determine, besides relative amounts of nitrates, their possible concentration under the influence of irrigation water in zones beyond the feeding range of the plant roots; (3) harvesting and threshing; (4) milling and analytical work on representative samples from each plat.

Fig. 1 illustrates the planting plan in 1910. A similar arrangement of plats was followed in 1911, 1912 and 1913, but in 1913 fallow plats were introduced in the Bluestem series adjacent to plats 1, 7, 13 and 19. In 1914, as will be noted later, the number of plats was reduced.

Fig. 2 shows the planting plan for 1914, 1915 and 1916. The original seed of the Sonora, grown for the entire seven years, and of the Palouse Bluestem and Little Club, grown for the first four years, was purchased from the Caldwell Milling and Elevator Company. Seed for the Minnesota Bluestem and Glyndon Fife, which were substituted for Palouse Bluestem and Little Club in 1914 and succeeding years, was sent from the central station at Moscow where those varieties had been grown for several

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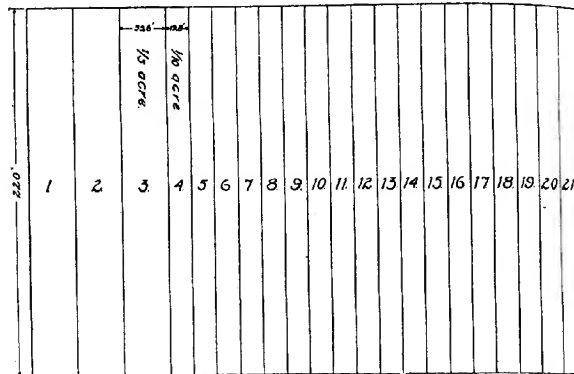


Fig. 1. Plan of planting followed in 1910, 1911, 1912 and 1913. In 1913 fallow plots (1 F, 7 F, 13 F and 19 F) of 1/20 acre each were introduced between 1 and 2, 7 and 8, 13 and 14, and 19 and 20.

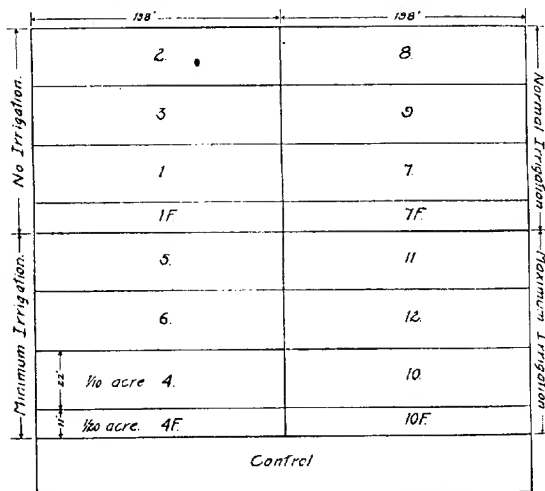


Fig. 2. Plan of planting followed in 1914, 1915 and 1916. Cropped plots were 1/10 acre, fallowed plots 1/20 acre each.

years from seed originally secured at University Farm, Minnesota. The seed was sown each year at the rate of 90 lbs. per acre with a common grain drill. All irrigation water was applied by flooding between borders and was very carefully measured. For nitrate determinations, soil samples were taken with a King soil tube. The nitrates were determined colorimetrically in an especially fitted-up laboratory in the basement of one of the Gooding public school buildings. At threshing time samples from each plat were retained for analytical and milling work as was seed for sowing on a corresponding plat the following season. In the analytical work the greatest emphasis was placed upon protein determinations in the wheat and flour and the greatest importance is now attached to those determinations. The total ash content and the percentage of phosphorus, as  $P_2O_5$ , and potassium, as  $K_2O$ , were determined each year to ascertain any possible relationships that might exist between irrigation and relative amounts of these constituents of the grain. The total ash was determined on each flour sample mostly as a check on the closeness of the milling operations.

The field observations, analytical data and comments upon the same follow.

#### THE CROP OF 1910,

The crop of 1910 was grown on raw sagebrush land well prepared of course for irrigation and planting. Nitrate determinations were not made but the concentration of that very essential soil component must have been low, probably not so low, however, as in 1911 and 1912; for there is on the surface of these semi-arid lands some decayed organic matter that owes its origin to the very thin growth of native grasses among the sagebrush. If this organic matter is not covered too deeply in the operations involved in clearing and levelling, its nitrification during the first year of cultivation must be rapid and of distinct benefit to the first crop. It is the common experience of farmers on semi-arid lands that yields of grain decline sharply from the first crop until the soil has been enriched with some form of organic matter. The reason unquestionably is the depletion of the small amount of available nitrogen originally present. The plats were sown on April 20. The least amount of water was given in two, and the largest amount in nine applications. The ripening period for the Sonora ranged from July 20, for the plat to which no water was applied, to July 29 for the plat on which most water was applied. The ripening period for the Bluestem and Little Club ranged from July 24, for plats given no water, to August 2 for plats



given the most water. The analytical data for the 1910 crop are presented in Table I.

From the increase in weights per 1000 kernels with increase in amounts of irrigation water up to at least one foot it would seem that a normally matured grain in any of the three series was not secured in 1910 with less than one foot of water. If the product of all plats except No. 2 Sonora is considered, there was a fairly consistent decrease in protein with an increase of irrigation water. If the comparison is limited to *normally* matured grain, however, the decrease in protein with increase in water was relatively small. As nearly as one might reasonably expect on the basis of crude protein and wet and dry gluten, the flours took the same relative position as the wheats from which they were ground. A maximum yield was possibly not obtained for the Little Club.

#### THE CROP OF 1911.

The crop of 1911 was grown on land that had been cleared of sagebrush in 1909 and used for barley and oat plats in 1910. It was plowed in the fall of 1910 and prepared for the wheat plats in the spring of 1911 by thorough disking. All plats were sown on March 25. The first irrigation was given June 1, the last July 27. The number of irrigations ranged from one to ten. There was a range of four days in the dates of ripening. Nitrates were determined in foot cores to a depth of six feet in all Bluestem plats; the data averaged for arbitrarily chosen periods of 15 and 16 days appear in Table II.

It will be noted that the supply of nitrates was low even at the beginning of the season. So low indeed was the supply that it is doubtful if the plants at any time had an adequate amount for maximum growth. The barley and oat crop of the preceding year of course drew heavily on the small stock of nitrogen originally present. The field and analytical data are given in Table III.

With the exception of three plats, No. 19 in the Bluestem series and Nos. 2 and 20 in the Sonora series, the product of each plat in 1911 was lower in protein than the seed from which it was grown. A lower yield of both grain and straw was also noticeable on most of the plats.



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Table II.  $\text{NO}_3$  in parts per million on dry soil, 1911.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Periods for which nitrate data were averaged*						
				May 16-31 <i>a</i>	June		July		August 1-16 <i>f</i>	
					1-15 <i>b</i>	16-30 <i>c</i>	1-15 <i>d</i>	16-31 <i>e</i>		
1	0	000	1		2.9	2.0	1.6	2.0		1.8
			2		2.8	1.8	1.3	0.9		1.1
			3		5.5	2.9	2.9	1.9		2.1
			4		6.3	1.9	2.4	2.2		1.6
			5		5.3	2.1	2.7	1.5		2.1
			6		2.7	1.7	2.1	1.8		2.3
4	1	.479	1		3.7	1.6	1.8	1.7		1.3
			2		3.1	1.5	1.4	1.0		0.8
			3		5.0	2.8	2.5	1.3		2.1
			4		5.8	3.1	3.2	2.4		3.6
			5		6.5	3.6	4.7	4.5		4.7
			6		6.9	5.8	5.1	5.7		4.7
7	3	1.285	1		3.0	1.8	1.4	2.3		1.7
			2		4.5	1.2	1.3	1.1		1.1
			3		6.4	2.7	2.3	2.1		2.7
			4		8.3	4.5	3.1	3.6		3.7
			5		9.2	4.8	3.1	7.2		3.7
			6		12.1	5.4	4.0	13.2		2.1
10	5	1.516	1		2.5	2.3	1.7	2.4		4.2
			2		1.8	1.5	2.1	0.9		1.4
			3		7.3	4.5	2.2	1.8		2.1
			4		5.6	4.8	2.5	2.5		3.1
			5		8.6	8.3	4.7	2.7		3.9
			6		11.3	9.3	5.2	4.4		3.8
13	4	1.737	1		3.0	1.5	1.3	1.6		1.5
			2		3.0	1.2	1.2	1.7		0.9
			3		5.9	1.7	1.3	1.3		1.3
			4		8.1	2.4	2.8	1.6		2.6
			5		6.7	4.3	4.6	3.6		2.9
			6		6.6	5.8	9.1	2.9		5.5
16	7	2.558	1		2.6	1.3	1.3	2.1		5.5
			2		3.0	1.1	1.2	0.9		1.5
			3		7.3	2.0	1.4	1.2		1.9
			4		7.4	3.8	2.4	1.3		2.6
			5		5.6	5.3	2.2	3.1		2.9
			6		6.6	7.2	3.0	4.0		3.3
19	10	2.820	1		2.2	1.4	1.4	1.7		4.0
			2		1.9	1.2	1.1	0.9		1.4
			3		2.1	1.0	1.0	1.8		0.4
			4		2.3	0.8	1.0	1.8		0.4
			5		2.9	1.4	1.1	2.0		0.8
			6		1.8	1.9	2.0	3.9		1.0

\* Samples were taken for the determination of their nitrate content on the following dates: June 1, 3, 6, 8, 12, 15, 20, 22, 26 and 28; July 6, 10, 12, 17, 20, 24 and 27; and August 1, 8 and 15.

Table III. *Field and analytical data on wheat and flour, crop of 1911.*

Number	Laboratory	Variety	Yields			Weight			Wheat				Flour				
			Total grain, acre-	Straw per acre, tons	Grain per acre, bushels	per 1000 kernels, grams	per bushel, lbs.	Moisture per cent.	Crude protein NX 64 on dry basis per cent.	Ash per cent.	P <sub>2</sub> O <sub>5</sub> in grain per cent.	K <sub>2</sub> O in grain per cent.	Moisture per cent.	Ash per cent.	Crude protein NX 5-7 per cent.	Gluten wet per cent.	dry per cent.
1	462	Bluestem	-000	15.87	.70	32.46	56½	8.90	11.41	12.53	1.99	1.08	.57	10.30	33.03	12.99	
4	463	"	-479	18.47	.78	30.38	53	9.65	10.96	12.14	2.01	—	—	10.48	28.83	11.22	
7	464	"	1.285	22.05	1.00	35.10	57½	9.00	10.96	12.05	2.02	1.06	.57	10.31	30.59	11.88	
10	465	"	1.516	22.85	.92	34.82	57½	9.14	10.53	11.59	1.99	—	—	10.35	30.67	12.97	
13	466	"	1.737	26.08	1.00	32.96	58½	8.72	10.35	11.34	1.98	1.06	.57	9.99	30.91	12.65	
16	467	"	2.558	24.54	1.16	33.80	57	8.77	10.27	11.26	2.05	—	—	10.73	29.51	11.79	
19	468	"	2.820	17.03	.68	34.86	58	8.73	11.23	12.30	2.00	1.06	.59	10.24	35.87	14.04	
3	471	Little Club	-000	17.72	.72	23.38	57	8.88	11.23	12.33	1.99	1.07	.59	10.10	28.24	10.23	
6	472	"	-417	24.42	.70	25.06	58	8.14	10.88	11.84	2.02	—	—	10.08	27.02	10.27	
9	473	"	1.148	28.49	1.05	29.40	57½	8.81	10.62	11.65	1.96	1.02	.61	10.34	25.09	9.95	
12	474	"	1.451	30.35	1.05	28.98	57½	8.43	10.35	11.30	2.09	—	—	10.31	25.32	10.02	
15	475	"	1.842	26.06	.93	29.18	58	9.32	10.69	11.13	2.04	1.06	.58	10.34	26.46	10.37	
18	476	"	2.161	18.69	.64	28.90	57½	9.48	10.18	11.25	2.10	—	—	10.35	26.29	9.79	
21	477	"	2.834	16.14	.56	29.72	58	9.27	10.96	12.08	2.07	1.09	.56	9.98	29.92	11.50	
2	453	Sonora	-000	16.22	.58	32.00	61	8.55	10.69	11.69	1.86	1.05	.52	10.99	28.31	11.91	
5	454	"	-370	18.26	.57	31.40	60	8.45	10.35	11.33	1.95	—	—	11.33	27.98	10.82	
8	455	"	1.184	19.86	.78	34.88	59	9.45	10.18	11.24	1.97	1.03	.52	10.69	27.71	10.52	
11	456	"	1.374	23.15	.96	35.50	60	9.12	10.44	11.49	1.96	—	—	10.49	27.18	10.40	
14	457	"	1.861	18.86	.79	34.50	59½	9.27	10.18	11.22	2.03	1.06	.55	10.42	27.91	11.16	
17	458	"	2.853	22.51	.92	34.50	60	9.38	9.92	10.35	1.97	—	—	10.59	26.82	10.29	
20	459	"	3.156	13.20	.53	34.28	60	9.20	11.76	12.35	2.00	1.12	.55	10.18	26.30	10.43	

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#### THE CROP OF 1912.

The crop of 1912 was grown on the same land that grew the crop of 1911. The ground was plowed in the spring, disked, harrowed and floated in preparation for planting and irrigation. The borders of each plat were identical with those of the corresponding one of the preceding season. The sowing was made April 1. The first irrigation was given June 3, the last July 25. As in 1911 the number of irrigations ranged from one to ten and again there was a range of four days in the dates of ripening. The nitrate data are presented by periods in Table IV.

The concentration of nitrates was again very low.

The field and analytical data are given in Table V.

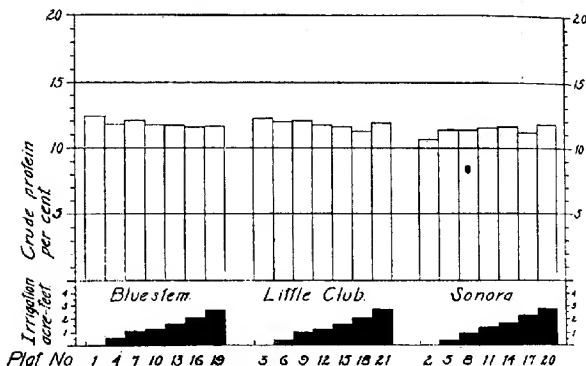


Fig. 3. Crude protein of wheats grown for three years with varying amounts of irrigation water. Drawn from data presented in Table VI.

The yield of grain on most of the plats was heavier than on corresponding plats of the preceding season, but as a general rule the yield of straw was lighter. For the major portion of the plats the yields of both grain and straw were lower, however, in 1912 than in 1910. With the exception of plat 4 in the Bluestem series and plats 3 and 6 of the Little Club series, the product of each plat appeared to be normally developed. In general there was a still further decline in the protein content of the grain from each plat, but variations in the protein content of the grain were not strictly in keeping with variations in the amounts of irrigation water used.

Table IV.  $\text{NO}_3$  in parts per million on dry soil, 1912.

Plat No.	Number of irri- gations	Total irriga- tion, acre- feet	Foot zone repre- sented by soil sample	Periods for which nitrate data were averaged*					
				May 15-31 a	June		July		August 1-12 f
					1-15 b	16-30 c	1-15 d	16-31 e	
1	0	.000	1		2.4	2.7	1.7	1.0	1.5
			2		1.9	1.8	.6	.5	.4
			3		3.1	1.8	.9	1.1	.8
			4		3.8	2.0	2.6	1.6	.9
			5		5.9	3.7	2.6	1.8	1.3
			6		5.3	4.6	4.9	2.8	2.0
4	1	.589	1		3.1	2.6	1.6	1.3	1.3
			2		1.8	2.0	.7	.8	.9
			3		1.7	1.5	.6	.6	.6
			4		2.3	1.8	1.4	1.2	3.1
			5		6.4	2.4	2.3	1.7	4.5
			6		6.7	2.8	2.1	4.0	4.1
7	3	1.244	1		2.5	2.7	1.6	1.4	2.5
			2		1.2	2.1	.6	.7	.7
			3		3.1	2.9	.8	.5	.9
			4		4.4	3.3	1.5	1.3	2.2
			5		6.3	5.9	3.0	2.9	3.2
			6		6.5	9.4	5.5	3.1	4.0
10	4	1.275	1		2.6	3.0	1.6	1.3	1.5
			2		2.0	2.0	.7	.4	.6
			3		2.2	1.7	.9	.7	.4
			4		2.2	2.0	.8	1.2	.5
			5		2.9	2.5	1.2	1.5	1.5
			6		4.7	3.6	2.8	4.0	2.9
13	6	1.806	1		3.2	2.6	1.2	1.5	1.1
			2		1.8	1.7	.5	.3	.7
			3		2.0	1.7	.6	.2	.6
			4		2.0	1.4	1.1	.5	.4
			5		2.5	2.3	1.3	2.0	.7
			6		4.0	4.1	2.5	5.1	1.8
16	7	2.381	1		4.8	2.4	1.5	1.3	2.2
			2		2.3	1.8	.7	.4	.7
			3		2.6	1.6	.7	.5	.8
			4		2.7	1.6	1.2	1.1	.9
			5		3.6	1.9	1.8	7.6	2.1
			6		4.0	2.7	4.7	2.8	2.3
19	10	2.638	1		3.1	2.7	1.1	1.3	1.4
			2		1.8	1.7	.4	.2	.2
			3		2.3	1.5	.4	.2	.3
			4		2.3	1.7	.7	.5	.4
			5		2.1	2.7	1.1	.9	.4
			6		3.1	3.2	1.5	1.0	.5

\* Samples were taken for the determination of their nitrate content on the following dates: June 3, 6, 10, 14, 20, 24, 26 and 29; July 2, 5, 9, 11, 15, 18, 23, 26 and 30; and August 5 and 12.

Table V. *Field and analytical data on wheat and flour, crop of 1912.*

Plat	Number	Variety	Wheat										Flour						
			Total irri- gation, ac- re-feet	Grain per ac- re, bu.	Straw per ac- re, tons	Yields		Weight		Crude protein NX 04			Mois- ture		Ash per cent.	Crude protein per cent.	Gluten		
						per 1000	per acre, bu.	per acre, lbs.	per cent.	Mois- ture per cent.	on dry basis per cent.	Ash per cent.	P <sub>2</sub> O <sub>5</sub> per cent.	K <sub>2</sub> O per cent.	per cent.	per cent.	wet per cent.	dry per cent.	
1	498	Bluestem	900	18.13	54	34.70	56½	10.41	9.21	10.28	1.90	.93	.54	13.19	.44	7.36	26.82	8.86	
4	499	"	589	18.40	63	31.30	56	9.81	9.12	10.11	1.91	—	—	13.14	.43	7.12	24.47	8.16	
7	500	"	1244	25.51	99	37.90	56	9.13	9.82	10.81	1.97	1.03	.56	13.16	.49	7.02	29.23	9.55	
10	501	"	1275	25.42	99	37.80	58½	9.66	9.48	10.49	1.91	—	—	13.00	.49	7.44	26.68	8.78	
13	502	"	1806	24.07	91	38.56	58	10.55	10.18	11.38	1.91	1.01	.57	13.13	.56	8.40	30.20	10.11	
16	503	"	2381	27.54	100	38.16	59	10.49	10.18	11.37	1.92	—	—	13.05	.50	8.16	30.05	9.95	
19	504	"	2638	33.71	118	41.14	—	10.11	9.82	10.93	1.94	1.02	.58	13.20	.51	7.76	28.12	9.37	
Little Club																			
3	512	"	—	400	17.37	50	25.90	55½	9.60	9.04	10.00	1.88	.93	.56	13.37	.48	7.04	22.60	7.45
6	513	"	—	481	18.71	60	28.88	57	9.00	9.21	10.12	1.96	—	—	13.21	.45	7.36	27.53	8.95
9	514	"	1273	23.46	75	31.26	58	9.83	9.74	10.80	1.99	1.01	.60	13.70	.53	7.84	31.34	10.51	
12	515	"	1272	24.46	81	31.40	58½	10.00	9.48	10.53	2.02	—	—	13.90	.51	7.52	30.90	10.58	
15	516	"	1815	26.48	92	32.30	58½	9.67	10.18	11.27	2.01	1.01	.61	13.55	.51	8.16	34.04	11.40	
18	517	"	2146	25.60	92	31.00	58½	9.36	9.65	10.65	2.00	—	—	13.44	.48	7.68	30.34	9.98	
21	518	"	2436	30.76	108	31.98	57½	9.24	10.09	11.12	2.07	1.04	.61	13.48	.51	7.60	31.20	10.18	
Sonora																			
2	505	"	400	15.21	41	33.94	58	10.04	8.98	9.85	1.78	.94	.50	13.49	.44	7.68	24.00	8.43	
5	506	"	343	20.12	55	34.44	58	9.73	9.12	10.10	1.87	—	—	13.64	.52	7.60	25.57	8.66	
8	507	"	1190	20.13	56	36.84	60	9.04	9.06	10.51	1.82	1.03	.54	13.32	.50	7.84	28.35	9.34	
11	508	"	1179	29.59	64	37.16	60	9.31	9.39	10.35	1.96	—	—	13.49	.50	7.44	25.63	8.36	
14	509	"	2125	24.73	82	37.44	61	9.81	9.92	11.00	1.95	1.03	.54	13.19	.53	8.00	28.21	9.10	
17	510	"	2216	29.51	108	38.20	60	10.15	9.82	10.93	1.93	—	—	13.03	.66	8.48	29.18	9.18	
20	511	"	2798	29.67	100	37.04	60	9.51	9.05	10.66	1.94	1.00	.54	13.22	.59	7.98	27.49	8.38	

Table VI. *Averages for field and analytical data on wheat and flour, crops of 1910, 1911 and 1912.*

Plot	Number Laboratory	Variety	Wheat										Flour						
			Total irri- gation, acre- feet	Yields		Weight		Mois- ture per cent.	Crude protein XX 64		P <sub>2</sub> O <sub>5</sub> in per cent.	K <sub>2</sub> O in per cent.	Ash per cent.	Mois- ture per cent.	Crude protein XX 67 per cent.	Gluten			
				Grain per acre bu.	Straw per acre tons	per 1000 kernels, bu.	per 1000 kernels, lbs.		on dry basis per cent.	per cent.						wet per cent.	dry per cent.		
—	211	Bluestem*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—		
1	1	"	-000	13-67	-52	28-93	54-8	9-44	11-23	12-39	1-93	1-00	-57	11-19	-48	9-24	34-46	11-73	
4	1	"	-533	18-52	-75	28-94	53-8	9-58	10-73	11-86	1-99	—	—	11-24	-48	9-12	31-24	10-88	
7	10	"	1-081	23-61	-90	33-38	55-7	9-46	10-95	12-10	2-02	-1-05	-58	11-20	-49	9-12	32-46	11-13	
10	7	"	1-211	26-23	-107	34-60	57-0	9-75	10-90	11-75	1-97	—	—	11-17	-46	8-62	31-92	11-44	
13	16	"	1-585	27-83	-104	35-75	57-8	9-87	10-54	11-69	1-94	-1-02	-57	11-01	-48	8-62	32-07	10-85	
16	13	"	2-124	28-53	-125	35-03	57-5	9-85	10-43	11-57	1-99	—	—	11-25	-49	8-34	31-10	10-85	
19	19	"	2-648	27-91	-98	37-59	57-5	9-56	10-49	11-60	1-96	-1-03	-59	11-10	-50	8-73	31-84	11-14	
—	212	Little Chub*	—	—	—	—	28-44	—	9-50	13-03	14-40	-1-50	-92	-63	—	—	—	—	—
3	3	"	-000	14-39	-52	28-01	55-2	9-56	11-07	12-25	2-05	-1-00	-57	10-72	-54	9-11	32-67	10-99	
6	9	"	-444	20-19	-75	25-53	56-3	9-11	10-80	11-90	2-05	—	—	10-64	-51	9-14	32-37	11-16	
9	6	"	1-005	24-86	-89	29-52	57-8	9-68	10-92	12-10	2-01	-1-02	-60	10-98	-51	9-13	33-61	11-63	
12	15	"	1-210	28-47	-98	29-61	57-7	9-57	10-62	11-74	2-04	—	—	11-02	-51	8-94	32-40	11-03	
15	13	"	1-583	29-18	-103	30-64	58-3	9-78	10-78	11-59	2-00	-1-03	-60	10-93	-51	8-91	32-42	11-06	
18	18	"	2-031	27-41	-95	30-51	58-3	9-91	10-12	11-24	2-02	—	—	10-91	-49	8-69	31-04	10-51	
21	21	"	2-769	30-20	-103	31-09	57-8	9-85	10-71	11-89	2-03	-1-04	-59	10-81	-49	8-59	31-75	10-89	
—	213	Nature*	—	—	—	—	37-94	—	8-50	10-24	11-19	-1-80	-96	-50	—	—	—	—	—
2	2	"	-000	13-83	-43	31-02	59-0	9-49	9-65	10-66	1-75	-98	-51	11-19	-44	8-77	28-91	10-40	
5	5	"	-358	19-61	-51	31-28	59-2	9-16	10-29	11-33	1-88	—	—	11-38	-48	8-47	29-38	10-23	
8	8	"	-969	20-22	-66	34-50	59-8	9-31	10-29	11-35	1-94	-1-00	-52	10-85	-51	8-59	30-59	10-51	
11	11	"	1-166	25-53	-78	34-03	60-2	9-54	10-41	11-51	1-94	—	—	10-88	-49	8-83	28-63	9-85	
14	14	"	1-695	25-26	-89	35-82	60-2	9-63	10-47	11-59	1-95	-1-02	-52	10-81	-51	8-59	29-60	10-49	
17	17	"	2-223	28-84	-110	35-66	59-3	9-81	10-06	11-16	1-92	—	—	10-84	-56	8-38	28-63	10-12	
20	20	"	2-769	25-98	-89	35-50	60-3	9-25	10-08	11-77	2-00	-1-04	-53	10-71	-55	8-52	28-13	9-71	

\* Original seed.

### 308 *The Protein Content of Wheat grown with Irrigation*

For reasons that will become perfectly obvious in the discussion of 1913 and succeeding years' work, the field and analytical data for 1910, 1911 and 1912 have been summarized for presentation in Table VI.

In studying this table it is well to remember that thus far the soils on which these wheats were grown had undergone no treatment looking toward their enrichment with organic matter over their original very low content. Under conditions of growth similar to these it would seem that there are between rather wide limits no outstanding relationships between amounts of water used and the protein content of the harvested grain or of the flour milled from it. Fig. 3 was drawn from the averages for irrigation and wheat protein given in Table VI.

#### THE CROP OF 1913.

The land on which the 1913 crop was grown was cleared of sagebrush and levelled in 1909. In the spring of 1910 it was sown to alfalfa for the conduct of experiments in seed production and rate-of-seeding tests. It was plowed in the fall of 1912, at which time the third growth of alfalfa was turned under. The ground was left in the rough during the winter, replowed in the spring of 1913 and prepared in the usual way for irrigation and sowing. The plats were sown April 28. The first irrigation was given June 3, the last July 28. The number of irrigations ranged from one to nine. The dates of ripening ranged from August 19 to August 25 for the Bluestem and Sonora series and from August 11 to August 24 for the Little Club series. The spring plowing caused the loss of so much of the stored precipitation that the plants on all three plats which received no water made no growth after the booting stage and of course were not harvested. In all of the plats some alfalfa persisted in spite of the double plowing given in preparation of the ground for sowing. In the belief that some definite information could be secured from them regarding nitrification processes, fallow plats were provided adjacent to Nos. 1, 7, 13 and 19 of the Bluestem series. As regards irrigation, the treatment of these plats was in all ways identical with that given the corresponding cropped plats. The nitrate data by periods for the year are given in Table VII.

A remarkable increase in nitrates in the wheat plats over the two preceding years is at once evident from the most casual examination of this table. There was noticeable, too, a remarkable accumulation of nitrates in the four fallow plats especially during the early part of the growing season. The field and analytical data for the year are given in Table VIII.

Table VII.  $\text{NO}_3$  in parts per million on dry soil, 1913.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Periods for which nitrate data were averaged*					
				May 16-31 a	June		July		August 1 f
					1-15 b	16-30 c	1-15 d	16-31 e	
1	0	.000	1		71.7	84.1	47.0	75.3	64.0
			2		25.0	12.0	2.9	8.0	4.8
			3		3.2	1.2	0.0	1.6	0.0
			4		0.8	0.2	0.0	0.0	0.0
			5		0.4	0.0	0.0	0.0	0.0
			6		0.0	0.0	0.0	0.0	0.0
1 F	0	.000	1		119.8	49.0	79.0	103.3	95.0
			2		17.8	15.3	6.3	11.7	12.0
			3		2.1	1.2	1.6	0.9	0.0
			4		0.6	0.0	0.0	0.0	0.0
			5		0.5	0.6	0.0	0.0	0.0
			6		0.0	0.0	0.0	0.0	0.0
4	1	.299	1		87.2	27.3	16.0	26.0	22.0
			2		61.0	45.0	21.0	31.3	20.0
			3		8.1	12.6	4.4	15.8	8.7
			4		1.3	1.8	0.5	5.7	0.0
			5		0.5	1.3	1.4	0.0	0.0
			6		0.0	0.6	0.0	0.0	0.0
7	2	.515	1		61.5	50.3	21.0	29.2	20.0
			2		29.2	21.0	21.0	4.9	8.0
			3		5.1	4.0	0.7	2.8	0.0
			4		1.5	2.0	0.0	0.6	0.0
			5		0.9	0.9	0.0	0.4	0.0
			6		1.0	0.0	0.0	0.0	0.0
7 F	2	.515	1		90.0	71.3	97.0	26.0	24.0
			2		53.0	55.3	29.0	35.0	6.9
			3		9.5	19.6	11.6	6.5	11.0
			4		1.7	0.9	2.8	1.2	0.0
			5		1.4	0.9	2.4	0.0	0.0
			6		1.5	0.3	0.0	0.0	0.0
10	3	.541	1		54.0	38.1	2.7	3.5	3.9
			2		27.0	14.5	1.5	1.7	0.0
			3		4.7	5.2	0.0	0.0	1.7
			4		1.8	0.3	0.0	0.0	0.0
			5		0.7	0.7	0.0	0.0	0.0
			6		0.0	0.3	0.0	0.0	0.0

\* Samples were taken for the determination of their nitrate content on the following dates: June 3, 7, 10, 14, 17, 24 and 30; July 7, 11, 16, 21 and 28; and August 1.



310 *The Protein Content of Wheat grown with Irrigation*

Table VII (continued).

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Periods for which nitrate data were averaged*					
				May 16-31 <i>a</i>	June		July		August 1 <i>f</i>
					1-15 <i>b</i>	16-30 <i>c</i>	1-15 <i>d</i>	16-31 <i>e</i>	
13	4	.978	1		38.5	6.1	2.6	3.0	2.4
			2		30.5	14.7	0.3	0.5	1.6
			3		5.0	6.6	1.8	0.0	4.1
			4		1.9	1.0	2.1	0.0	0.0
			5		1.1	0.3	0.8	0.0	0.0
			6		0.4	0.0	0.0	0.0	0.0
13 F	4	.978	1		53.3	65.0	12.9	23.3	23.0
			2		25.8	50.6	27.5	22.4	18.0
			3		5.5	2.4	3.3	4.2	1.7
			4		0.6	0.4	0.0	0.3	0.0
			5		1.1	0.0	0.0	0.0	0.0
			6		0.7	0.0	0.0	0.0	0.0
16	5	1.182	1		65.5	62.3	4.1	5.4	1.0
			2		40.5	53.3	3.6	4.6	1.3
			3		6.2	1.5	15.0	5.5	2.6
			4		1.5	0.3	0.0	0.0	8.6
			5		1.2	0.0	0.0	0.0	0.0
			6		0.5	0.0	0.0	0.0	0.0
19	9	1.863	1		69.3	12.4	1.6	1.4	1.8
			2		39.7	56.3	2.1	0.8	1.8
			3		15.5	27.0	34.5	17.0	26.0
			4		2.7	0.9	15.5	9.6	7.9
			5		1.8	0.0	0.8	1.4	0.0
			6		1.4	0.0	2.0	0.6	0.0
19 F	9	1.863	1		46.3	33.5	7.9	12.4	8.2
			2		32.0	71.0	7.0	4.3	8.2
			3		16.8	60.7	16.5	18.2	19.0
			4		3.5	7.8	22.7	29.9	27.0
			5		1.3	0.0	31.5	4.8	9.0
			6		1.2	0.0	25.0	16.3	40.0

\* Samples were taken for the determination of their nitrate content on the following dates: June 3, 7, 10, 14, 17, 24 and 30; July 7, 11, 16, 21 and 28; and August 1.

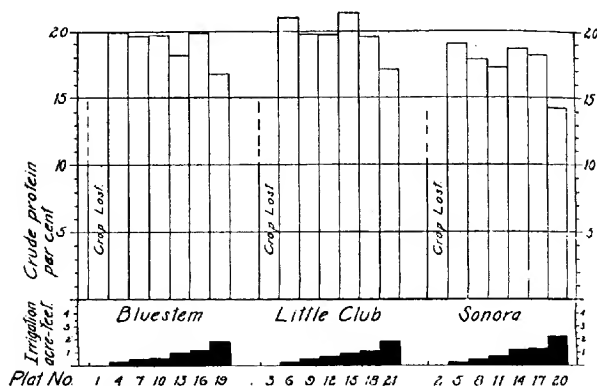
For the first time in the growth of these wheats they had whatever advantage there is in a seed bed enriched with nitrogen-containing organic matter. In spite of the unfavourable season there was on plats given the larger amounts of water a fairly sharp increase in yields of grain and straw. With each variety the highest yields were secured with maximum irrigation. There was, however, a marked tendency

Table VIII. *Field and analytical data on wheat and flour, crop of 1913.*

Plat	Number	Laboratory	Variety	Wheat										Flour						
				Total grain, acres	Grain, per acre, bu.	Straw, per acre, tons	Yields	Weight		Crude protein NX 6½			P <sub>2</sub> O <sub>5</sub> in grain, per cent.	K <sub>2</sub> O in grain, per cent.	Moisture, per cent.	Ash, per cent.	Crude protein NX 5.7, per cent.	Gluten, wet, per cent.	Gluten, dry, per cent.	
1	—	—	Bluestem	4000	Lost															
4	1	—	"	299	17-16	57	30-58	57	8-31	18-21	19-86	1-82	—	—	—	11-96	51	14-41	61-73	20-64
7	571	—	"	515	25-96		1-05	26-99	55½	8-85	17-86	1-97	1-03	—	—	11-79	50	14-10	61-05	20-82
10	572	—	"	541	27-68	1-40	26-40	65	8-58	17-85	19-64	2-10	—	—	—	11-80	50	13-66	59-73	19-52
13	573	—	"	978	28-40	1-38	36-36	58½	8-39	16-57	18-13	1-97	1-08	—	—	11-70	49	13-14	53-91	17-02
16	574	—	"	1-182	23-85	1-55	32-96	37	7-86	18-26	19-82	2-14	—	—	—	11-41	53	14-28	60-25	20-47
19	575	—	"	1-863	41-08	2-07	31-34	56½	9-26	15-21	16-74	1-92	1-02	—	—	12-24	47	12-16	49-18	15-47
3	—	—	Little Club	4000	Lost															
6	584	—	"	258	22-31	71	23-19	55	8-12	19-35	21-06	2-04	—	—	—	11-84	58	16-04	62-15	23-60
9	585	—	"	500	32-02	1-19	21-60	56	8-84	17-05	19-74	2-16	1-13	—	—	12-34	48	15-12	58-94	20-01
12	586	—	"	600	22-96	1-21	23-96	56½	8-10	18-10	19-70	2-10	—	—	—	12-29	50	14-45	57-09	21-01
15	587	—	"	930	22-01	1-14	29-98	59	8-86	19-53	21-43	2-13	1-16	—	—	12-33	58	15-33	60-40	22-31
18	588	—	"	1-997	42-23	2-19	21-08	56	8-86	17-91	19-54	2-17	—	—	—	12-32	58	15-01	60-90	22-62
21	589	—	"	1-836	50-03	2-01	28-74	58	9-07	15-72	17-10	2-00	1-05	—	—	12-51	54	11-98	46-17	15-80
2	—	—	Sonora	4000	Lost															
5	577	—	"	264	18-48	53	26-22	60	8-73	17-32	18-98	1-90	1-02	—	—	11-69	56	12-92	49-18	17-26
8	578	—	"	475	30-65	92	31-32	58½	8-71	16-24	17-79	1-83	—	—	—	11-85	56	13-30	51-61	17-42
11	579	—	"	691	37-71	1-58	31-02	59	8-45	15-78	17-24	1-87	1-00	—	—	11-67	57	12-35	45-35	15-33
14	580	—	"	1-185	31-31	1-02	34-20	59½	8-41	17-05	18-62	1-98	1-09	—	—	11-41	62	14-26	51-87	17-38
17	581	—	"	1-255	31-47	1-20	29-61	59½	8-52	16-39	18-14	2-13	—	—	—	11-93	63	13-52	51-23	17-37
20	582	—	"	2-198	60-52	1-07	34-90	60½	8-83	13-03	14-29	1-94	1-06	—	—	12-17	54	10-56	42-05	13-94

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toward a lighter weight of kernel. The outstanding fact in the data for the year, however, is the very high protein content of the grain from each plat. In two out of the three series the highest protein wheats came from plats given the least water. In all three series the grain lowest in protein came from the plat given the most water. On plats given less than one foot of water, no definite relationship developed between amounts of water applied and the protein content of the grain. For the rather sharp increase in water over one foot, however, there was for each series a correspondingly sharp decline in the protein content of the harvested grain. These facts are shown graphically in Fig. 4.



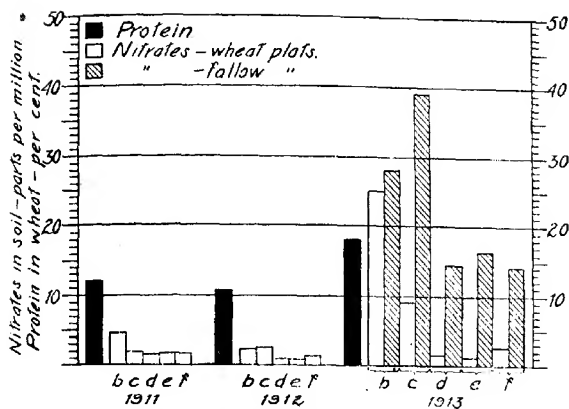


Fig. 5. Protein in Bluestem wheat from plats given *normal* irrigation in 1911, 1912 and 1913 and the average amounts of soil nitrates in the same plats to a depth of three feet by periods during the same years: *b* period, June 1 to 15 inclusive; *c* period, June 16 to 30 inclusive; *d* period, July 1 to 15 inclusive; *e* period, July 16 to 31 inclusive; and *f* period, August 1 to 16 inclusive.

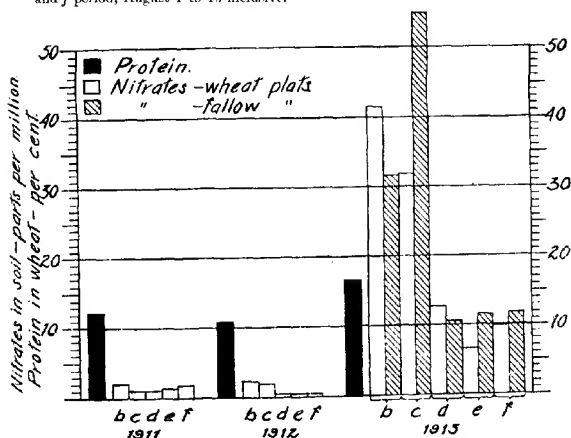


Fig. 6. Protein in Bluestem wheat from plats given *maximum* irrigation in 1911, 1912 and 1913 and the average amounts of soil nitrates in the same plats to a depth of three feet by periods during the same years.

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the same years. A very substantial difference between the soil's content of nitrates in June, 1911 and 1912, and that of June, 1913, cannot escape notice. To us it suggests very strongly a definite relationship between available soil nitrogen during the early growing period and the ability and readiness of the wheat plant to elaborate it into protein for storage later in the seed. The relative amounts of soil nitrates to the same depth of soil and for the same periods in plats given no irrigation and those given minimum irrigation in 1911, 1912 and 1913 might have been shown graphically with even more striking effect. Great activity on the part of nitrifying organisms during the early part of the growing season in 1913 is believed to be very clearly shown from the nitrate data of the fallow plats shown in Table VII.

#### THE CROP OF 1914.

In 1914 Minnesota Bluestem, Minnesota, No. 169, and Glyndon Fife, Minnesota, No. 163, were substituted for Palouse Bluestem and Little Club. The seed, as stated before, was sent from the central station where it had been grown from seed originally secured from University Farm, Minnesota. We wished to ascertain the behaviour of these hard spring wheats under irrigation. It was considered unnecessary to continue the use of so large a number of plats. The planting and irrigation scheme for 1914 and subsequent years called for plats of no irrigation, plats of minimum irrigation, plats of normal irrigation and plats of maximum irrigation for each variety and for fallow plats adjacent to each one in the Bluestem series. Fig. 2 shows a typical arrangement of the plats during 1914, 1915 and 1916.

The crop history of the land on which the 1914 crop was grown up to the fall of 1912 was identical with that of the land used for the crop of 1913. In 1913 it was planted to potatoes and produced a heavy crop. It was spring-plowed in 1914 and prepared as usual for sowing and irrigation. A cultivated crop thus intervened between one which makes decidedly for soil enrichment and the growing of this wheat crop. The plats were sown April 3. The first irrigation was given June 6, the last, July 29. The number of irrigations ranged from 1 to 11. There was a range in dates of ripening of ten days, the last to ripen being the plats given maximum irrigation, harvested August 14.

Nitrate data for all Bluestem plats and corresponding fallow plats are given in Table IX.

Again from the concentration of nitrates in the fallow plats, it would seem that there was great activity on the part of nitrifying organisms.

Table IX.  $\text{NO}_3$  in parts per million on dry soil, 1914.

Plat No.	Number of irri- gations	Total irriga- tion, acre- feet	Foot zone repre- sented by soil sample	Periods for which nitrate data were averaged*					
				May 15-31 <i>a</i>	June		July		August 1-19 <i>f</i>
					1-15 <i>b</i>	16-30 <i>c</i>	1-15 <i>d</i>	16-31 <i>e</i>	
1	0	-000	1	12.7	18.0	13.0	9.6	7.5	
			2	5.3	3.6	1.2	8.8	0.4	
			3	11.1	7.4	4.0	3.7	1.2	
			4	5.7	4.3	2.3	4.1	1.1	
			5	5.7	3.6	2.6	3.6	0.6	
			6	7.8	4.7	1.9	6.2	1.9	
1 F	0	-000	1	23.6	51.4	58.3	50.1	48.5	
			2	11.4	6.5	7.5	11.1	9.0	
			3	8.2	5.0	12.0	11.6	10.7	
			4	13.5	6.5	11.3	9.7	7.8	
			5	5.6	7.7	2.5	6.2	2.8	
			6	4.2	5.9	0.9	7.6	2.4	
4	1	-519	1	5.6	11.1	3.3	3.2	3.6	
			2	3.7	4.4	1.1	3.7	2.4	
			3	10.4	23.3	3.1	12.3	21.2	
			4	23.5	16.7	6.5	6.9	4.8	
			5	25.5	10.6	5.1	5.8	1.6	
			6	10.2	9.9	8.3	6.5	2.6	
4 F	1	-519	1	39.4	29.1	65.9	38.0	19.7	
			2	30.5	29.6	16.4	19.9	4.4	
			3	21.3	15.5	9.7	17.0	3.8	
			4	16.5	16.4	13.8	18.9	3.1	
			5	15.3	16.5	13.3	18.7	2.6	
			6	5.3	9.1	11.9	12.2	3.3	
7	3	1-012	1	9.4	9.7	5.1	4.8	7.2	
			2	16.5	2.7	4.6	6.2	61.6	
			3	44.7	19.0	37.4	8.9	31.1	
			4	28.6	7.0	21.4	7.7	3.9	
			5	17.1	6.2	10.5	3.1	1.1	
			6	6.9	3.6	6.3	3.7	1.4	
7 F	3	1-012	1	46.6	23.4	29.2	25.9	10.1	
			2	15.9	22.4	20.5	21.3	12.8	
			3	13.7	11.0	15.9	27.4	15.6	
			4	19.1	19.4	14.5	32.9	16.6	
			5	11.2	16.0	11.5	13.1	11.6	
			6	3.6	8.7	7.6	8.2	8.0	
10	11	2-341	1	6.3	2.3	1.1	6.2	1.9	
			2	7.1	0.9	0.3	1.6	0.8	
			3	3.9	0.6	0.1	0.9	2.8	
			4	4.3	9.1	4.8	5.7	3.8	
			5	5.1	10.7	11.9	6.2	2.6	
			6	7.8	19.2	15.2	8.6	3.9	
10 F	11	2-341	1	31.9	13.9	9.8	7.0	8.1	
			2	18.1	39.0	12.9	16.7	11.5	
			3	8.3	29.9	17.0	23.6	19.3	
			4	18.0	29.5	30.6	31.5	8.1	
			5	21.8	29.7	7.0	24.6	13.6	
			6	16.5	5.6	10.6	22.2	15.7	

\* Samples were taken for the determination of their nitrate content on the following dates: June 3, 8, 15, 18, 23 and 29; July 6, 10, 13, 17, 21, 27 and 31; and August 7, 14 and 19.

Table X. *Field and analytical data on wheat and flour, crop of 1914.*

Plat.	Number Laboratory	Variety	Total irri- ga- tion, ac- res	Yields			Weight			Crude protein N X 6.25 *				Flour					
				Grain per acre, bu.	Straw per acre, tons	per 1000 grams, lbs.	Mois- ture, per cent.	per cent.	on dry basis per cent.	Ash per cent.	P <sub>2</sub> O <sub>5</sub>		K <sub>2</sub> O		Ash per cent.	Crude protein N X 5.7 per cent.		Gluten	
											per cent.	in grain per cent.	per cent.	in grain per cent.		per cent.	in grain per cent.	per cent.	wet per cent.
1	669	Minn. Blue- stem	-000	20.58	1.20	25.10	55	9.39	17.75	19.59	1.92	1.05	.57	13.38	.57	13.58	44.00	14.45	
4	670	"	-513	26.45	1.60	25.90	55	10.59	17.08	19.10	1.94	1.08	.58	13.28	.54	14.02	50.20	16.27	
7	672	No. 169	1-012	32.23	1.90	32.30	57	10.17	17.67	19.64	1.93	1.09	.51	12.36	.58	14.45	49.50	15.03	
10	671	"	2-341	27.07	2.67	28.68	57 1/2	9.98	14.03	15.50	1.94	1.08	.54	12.82	.55	11.58	38.25	12.02	
2	673	Glyndon	-000	26.33	1.35	24.99	57	9.35	18.06	19.02	1.78	.95	.54	12.09	.57	13.86	52.50	16.05	
5	674	Fife, Minn.	-466	35.01	1.92	26.26	57	9.95	17.36	19.28	2.02	1.08	.53	12.46	.53	13.84	51.10	16.66	
8	676	No. 163	1-006	30.01	1.74	29.10	58	9.40	17.91	19.77	2.08	1.14	.53	12.67	.51	14.47	52.40	16.93	
11	675	"	2-544	32.90	2.47	30.16	57	9.66	13.11	14.51	1.66	1.09	.63	12.59	.50	10.88	35.00	11.52	
3	677	Sonora	-000	11.10	.86	27.08	58 1/2	9.92	17.32	19.23	1.93	1.08	.48	12.24	.57	14.26	49.35	16.78	
6	678	"	-420	23.03	1.58	22.86	55	10.50	16.00	17.88	1.96	1.03	.52	12.74	.43	10.58	32.00	12.62	
9	680	"	-870	20.78	1.50	20.21	55	10.77	16.44	17.30	2.08	1.04	.59	12.41	.56	12.08	42.90	16.26	
12	679	"	4-415	12.35	2.09	17.44	55	10.89	11.08	12.15	2.20	1.10	.65	12.84	.43	10.74	34.45	12.60	

The concentration of nitrates in the wheat plats of course for corresponding periods was much lower. The rather low initial content of the Bluestem plat given maximum irrigation and the sharp drop from that for the next two periods is noticeable.

The field and analytical data appear in Table X.

Plats 1 and 2 were unfortunately too close to the supply ditches and received some water by seepage that was not intended for them. The yields on them were unquestionably higher than one could reasonably expect in that section from no irrigation. The Sonora plat given maximum irrigation rusted badly and for that reason was low in yield. The yield on plat 11 was cut to some extent by the presence of an adobe spot. There was an unmistakable tendency toward lightness in weight. All samples of grain and flour were high in protein—those from plats given normal irrigation and less, extremely so. A close study of the data, however, gives no ground for assigning high protein content to lightness of kernel for the heavy-weight kernels were in the high-protein class. A close relationship between the supply of available nitrogen in the soil during the early period of growth and the protein content of the harvested grain again suggests itself. Plats given most water in each of the three series produced wheat of lowest protein content but again there was no *gradual* decrease of protein with increase of water in any series.

#### THE CROP OF 1915.

The crop history of the land on which the 1915 crop was grown is as follows: it was cleared of sagebrush in 1909, given over to the growth of barley in 1910 and to wheat in 1911 and 1912. In 1913 it was sown to red clover with barley as a nurse crop. Two crops were cut for hay in 1914. A heavy late growth was turned under with the plow in the fall. This land was prepared with the disk and harrow in the spring of 1915 for the wheat plats. This procedure again gave a soil considerably enriched over its native condition with nitrogen-containing organic matter.

The plats were sown April 5. The very dry spring necessitated the irrigation of *all* plats ten days later to insure a stand. The seventh and last irrigation was given July 26. There was a total range of 12 days in dates of ripening although most plats were harvested within a range of nine days. The nitrate data for the year will be found in Table XI.

There was perhaps a lower concentration of nitrates during the early-growing period than one might with good reason have anticipated.



318 *The Protein Content of Wheat grown with Irrigation*Table XI.  $\text{NO}_3$  in parts per million on dry soil, 1915.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Periods for which nitrate data were averaged*						
				May 16-31 <i>a</i>	June		July		August 1-10 <i>f</i>	
					1-15 <i>b</i>	16-30 <i>c</i>	1-15 <i>d</i>	16-31 <i>e</i>		
1	1	206	1		13.8	11.8	13.4	13.2		23.1
			2		7.4	3.8	6.1	8.1		7.0
			3		5.0	4.8	3.8	2.4		12.7
			4		0.0	5.5	1.0	0.7		3.8
			5		0.0	—	—	—		2.6
			6		2.4	—	—	—		—
1 F	1	206	1	144.0	114.0	194.0	157.0			262.0
			2	27.2	23.0	36.0	31.5			45.0
			3	17.5	14.6	14.8	13.2			26.3
			4	6.0	5.7	4.6	5.2			13.0
			5	0.9	—	—	—			4.6
			6	5.3	—	—	—			3.8
4	2	729	1	3.6	10.7	6.8	4.7			14.7
			2	7.5	5.4	2.6	1.3			6.4
			3	5.6	2.6	2.4	1.2			2.1
			4	0.0	0.6	1.5	0.5			2.1
			5	—	—	—	—			—
			6	—	—	—	—			—
4 F	2	729	1	88.0	72.0	119.3	56.5			130.0
			2	15.9	27.3	30.8	14.4			35.0
			3	4.4	11.9	11.7	14.5			18.6
			4	4.8	6.7	3.3	9.8			6.6
			5	—	—	—	—			3.6
			6	—	—	—	—			3.7
7	4	1-176	1	11.3	4.7	5.8	4.5			6.3
			2	2.1	4.2	3.3	2.2			2.9
			3	2.2	1.4	2.5	2.2			2.5
			4	0.8	0.0	0.7	0.4			2.2
			5	1.2	—	—	—			1.7
			6	—	—	—	—			1.9
7 F	4	1-176	1	62.5	73.0	77.0	48.0			54.2
			2	21.0	30.3	59.0	45.2			52.4
			3	3.7	16.8	17.9	52.5			31.2
			4	2.4	5.5	4.7	23.8			13.0
			5	1.9	—	—	—			10.9
			6	2.8	—	—	—			3.7
10	7	2-185	1	4.3	4.5	3.2	2.1			3.9
			2	3.4	2.1	1.8	1.1			3.1
			3	5.4	4.5	2.3	1.6			2.2
			4	2.4	2.8	5.4	0.3			2.7
			5	0.9	0.3	2.5	1.2			2.8
			6	0.0	0.0	0.8	2.4			11.4
10 F	7	2-185	1	101.9	84.3	41.2	33.4			10.3
			2	70.5	45.3	46.6	29.7			38.7
			3	24.9	23.8	58.3	24.2			49.1
			4	3.8	2.7	36.6	9.6			43.0
			5	2.8	0.9	20.0	2.8			75.5
			6	3.7	0.0	8.5	2.8			75.5

\* Samples were taken for the determination of their nitrate content on the following dates: June 10, 14, 19, 24 and 29; July 2, 5, 12, 19, 23, 26 and 29; and August 4 and 10.

Table XII. *Field and analytical data on wheat and flour, crop of 1915.*

Number of Plots	Labo- ratory	Variety	Total irri- gation, feet	Yield		Weight		Wheat				Flour		Gluten				
				Grain per acre,	Straw per ton,	per 100 bushels,	per cent.	Mois- ture, per cent.	per cent.	on dry basis	Ash per cent.	P <sub>2</sub> O <sub>5</sub> grain per cent.	K <sub>2</sub> O grain per cent.	Mois- ture, per cent.	Ash per cent.	Crude protein, per cent.	Gluten per cent.	
1	803	Minn. Blue- stem,	-206	19.82	1.94	26.73	52.1	10.58	17.69	19.87	1.82	1.30	-55	12.60	-53	13.89	48.65	16.11
4	804	Minn. Blue- stem, Minn.	-729	29.10	1.82	26.96	58	10.78	17.40	19.29	2.03	1.05	-66	13.80	-53	13.82	49.85	16.79
7	806	"	-1716	27.08	2.49	26.68	58	10.80	14.84	16.34	1.87	1.00	-53	13.15	-51	11.16	37.25	13.19
10	805	"	-2185	26.36	3.54	35.93	55.3	10.83	13.26	14.80	1.87	1.00	-52	13.18	-53	10.52	32.90	11.53
2	807	Glyndon	-304	22.10	1.26	23.72	56	10.41	17.93	20.04	1.86	-66	-56	12.87	-60	12.22	47.85	16.06
5	808	Effie, Minn.	-675	30.70	1.07	24.95	56	10.72	16.81	18.63	1.82	-98	-36	13.15	-54	13.38	47.75	16.23
8	810	No. 103	-1413	34.83	-2.78	24.22	58	11.77	14.65	15.92	1.64	1.04	-51	12.81	-45	11.76	33.30	12.69
11	809	"	-2660	26.20	3.42	33.77	55	11.38	15.42	14.85	1.64	-50	-50	12.83	-46	11.24	33.45	11.83
3	811	Sovereign	-173	24.62	1.47	23.63	57	12.18	17.21	19.60	1.76	-94	-53	13.16	-48	12.34	38.59	14.93
6	812	"	-773	26.16	1.41	23.92	55	9.86	14.36	16.15	1.69	-95	-48	12.79	-45	12.36	36.60	13.98
9	814	"	-1400	42.83	-2.22	27.42	59	10.46	13.69	15.02	1.93	1.04	-48	12.84	-46	10.86	36.90	14.28
12	813	"	-2522	30.36	2.53	37.82	59	10.55	12.24	1.70	1.01	-51	-51	12.71	-48	8.76	25.98	16.56

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An exceptionally great activity on the part of nitrifying organisms during the entire season, however, is indicated by the nitrate data for the fallow plats. A fair conclusion is that even though the nitrate concentration in the soil of the wheat plats was low, nitrification processes were going on with sufficient rapidity to supply the maximum requirements of the wheat plants.

The field and analytical data are given in Table XII.

There was a sharp increase in yields of grain and straw with increase of irrigation water. A plump, heavy kernel was produced with both normal and maximum irrigation. In each series the protein of the wheat for the first time gradually and consistently declined with the increase of irrigation water. With the exception of Sonora from plat 12, however, the protein of the wheat from each plat was high.

#### THE CROP OF 1916.

The crop history of the land which grew the crop of 1916 is practically identical with that used for the 1915 crop up to the spring of 1915. Wheat instead of barley was grown in 1910 and the red clover was sown in 1913 with oats instead of barley as a nurse crop. A heavy late growth of red clover was turned under in the fall of 1914 and potatoes were planted on it in the spring of 1915 for duty-of-water work. A cultivated crop, therefore, again intervened between one which makes for soil enrichment with nitrogen-containing organic matter and the grain crop. Immediately following the harvesting of the potato crop the ground was plowed and left in the rough over winter. In the spring it was worked down with a disk and harrowed in preparation for planting and irrigation.

The seed was sown April 24. The first irrigation was given June 7 and the last July 25. The minimum amount of water was given in one irrigation; the maximum amount in eight irrigations. The plats ripened between August 2 and August 15. Soil sampling for nitrate determinations began approximately two weeks earlier than in any preceding year. The nitrate data for the year are given in Table XIII.

A substantial nitrate concentration during the early periods of growth is noticeable for all of the wheat plats. The concentration of nitrates in the fallow plats was far less than for corresponding periods in 1915 but it was sufficient to indicate great activity on the part of the nitrifying organisms. The wheat plants had whatever advantage there is in an abundance of available soil nitrogen. The field and analytical data follow in Table XIV.

Table XIII.  $\text{NO}_3$  in parts per million on dry soil, 1916.

Plat No.	Number of irrigations	Total irrigation, acre-feet	Foot zone represented by soil sample	Periods for which nitrate data were averaged*						
				May	June		July		August	
				16-31 <i>a</i>	1-15 <i>b</i>	16-30 <i>c</i>	1-15 <i>d</i>	16-31 <i>e</i>	1-8 <i>f</i>	
1	0	.000	1	31.2	34.4	11.2	14.7	25.5	27.4	
			2	17.0	8.4	25.5	22.7	13.6	12.9	
			3	9.6	20.1	33.1	13.5	8.8	28.3	
			4	19.4	23.8	19.8	12.5	8.2	13.3	
			5	11.4	16.2	19.8	13.7	7.5	11.1	
			6	5.9	2.7	11.6	5.7	3.9	4.6	
1 F	0	.000	1	49.0	55.1	38.8	67.1	57.3	26.0	
			2	18.1	14.0	30.2	68.2	27.5	19.7	
			3	30.1	19.7	38.7	73.4	19.6	17.7	
			4	26.0	24.3	26.1	29.0	21.6	8.1	
			5	20.2	23.5	18.0	23.1	13.1	10.3	
			6	0.0	8.0	17.7	5.3	9.4	6.9	
4	1	.355	1	47.5	29.5	28.9	6.3	15.1	20.0	
			2	25.6	53.4	80.8	21.4	15.0	15.0	
			3	38.8	62.8	58.2	27.6	32.7	5.4	
			4	9.0	24.0	27.3	17.1	9.7	2.2	
			5	5.9	19.9	23.9	9.2	10.1	4.4	
			6	0.0	3.1	9.9	4.7	8.5	2.2	
4 F	1	.355	1	38.2	46.5	21.3	50.1	29.5	15.1	
			2	23.9	24.2	29.5	51.1	12.3	11.4	
			3	26.9	40.5	50.3	32.7	22.9	23.3	
			4	19.3	28.9	33.3	35.6	25.9	25.6	
			5	8.3	9.8	29.8	35.0	16.3	11.4	
			6	3.5	8.9	18.5	18.7	12.2	4.6	
7	3	.900	1	46.9	8.5	6.4	10.2	4.4	6.3	
			2	8.1	20.1	14.2	6.8	6.6	4.3	
			3	11.8	19.4	39.9	28.5	10.9	6.5	
			4	20.2	17.9	24.8	34.6	12.9	11.4	
			5	9.8	15.8	17.5	18.6	13.6	4.4	
			6	8.3	9.7	11.2	13.8	8.1	4.9	
7 F	3	.900	1	47.9	58.9	21.4	49.7	33.3	26.8	
			2	13.3	34.7	51.8	33.8	17.9	15.9	
			3	12.3	25.9	40.1	32.9	37.1	19.9	
			4	4.1	36.3	24.6	22.4	24.7	15.4	
			5	3.5	15.4	30.5	23.3	29.6	12.8	
			6	7.1	11.0	12.9	22.5	14.1	9.4	
10	8	1.879	1	30.0	18.9	21.9	8.0	3.0	4.4	
			2	6.9	9.3	14.0	8.1	4.8	2.3	
			3	10.1	14.5	16.1	10.7	5.5	4.7	
			4	13.2	15.5	16.9	22.8	7.1	2.3	
			5	5.2	13.1	10.6	21.5	4.7	2.3	
			6	5.3	16.5	5.9	14.5	6.3	2.3	
10 F	8	1.879	1	36.7	30.9	5.3	23.5	9.3	4.3	
			2	12.9	20.2	9.4	23.8	7.5	2.3	
			3	39.5	21.6	19.1	33.8	11.5	9.5	
			4	26.8	22.9	14.3	38.1	18.7	17.2	
			5	16.8	18.4	17.4	38.5	13.7	11.8	
			6	9.7	11.7	17.7	23.7	11.9	4.8	

\* Samples were taken for the determination of their nitrate content on the following dates: May 16 and 22; June 1, 6, 12, 20 and 28; July 7, 13, 19, 25 and 31; and August 8.

Table XIV. *Field and analytical data on wheat and flour, crop of 1916.*

Plot	Number	Laboratory	Variety	Total gation, acres.	Yields			Weight			Wheat				Flour			
					Grain acres.	Straw bu.	tons, acres.	per 1000 kernels, bu.	per cent.	Mois- ture, per cent.	Crude protein NX 64	on dry mat- ter, per cent.	Ash per cent.	P <sub>2</sub> O <sub>5</sub> in grain per cent.	K <sub>2</sub> O in grain per cent.	Mois- ture, per cent.	Ash per cent.	Crude protein NX 5.7 per cent.
1	930	Minn. Blue-	-000	22.60	1.03	28.91	54	9.98	17.64	19.60	1.87	1.00	.52	11.69	.62	14.46	56.90	17.17
4	931	stern, Minn.	-355	26.73	1.61	29.51	55	8.78	18.72	20.52	1.96	1.08	.54	12.09	.64	15.39	53.05	16.86
7	932	No. 169	-900	35.92	1.92	37.07	60	8.88	16.88	18.53	1.96	1.05	.48	12.32	.64	12.90	44.25	13.46
10	933	"	-1.879	33.02	1.97	36.39	56	9.92	14.19	15.76	1.89	1.03	.49	12.28	.59	11.50	40.05	16.98
2	934	Glyndon	-000	28.10	1.12	27.93	55	9.79	18.21	20.19	1.83	.93	.50	11.73	.51	15.49	55.05	17.35
5	935	Fife, Minn.	-339	31.00	1.55	26.71	55	10.04	18.83	20.93	2.01	1.08	.52	12.26	.52	15.69	61.15	18.80
8	936	No. 163	-943	44.88	2.12	34.73	60	10.09	17.47	19.43	1.97	1.08	.48	12.09	.66	14.16	52.10	15.83
11	937	"	-1.659	42.30	2.20	36.77	57	10.73	14.71	16.48	1.99	1.05	.47	11.79	.49	12.38	45.10	14.10
3	926	Sonora	-000	24.72	.82	28.21	55½	10.23	16.21	18.06	1.82	.92	.50	11.07	.49	12.71	48.15	16.31
6	927	"	-354	33.92	1.37	29.03	55½	9.36	15.63	17.24	1.99	.98	.54	11.47	.54	12.78	50.65	17.27
9	928	"	-887	48.87	1.48	38.64	61	9.96	14.93	16.68	1.75	.97	.47	12.02	.54	12.30	46.90	16.05
12	929	"	-1.367	44.25	1.47	39.94	60½	10.00	12.44	14.06	1.94	1.00	.51	11.69	.51	10.26	33.25	11.20

Maximum production in 1916 was reached in each series with the application of the normal irrigation. The kernels attained exceptional weight with the larger amounts of water. With increase in amounts of irrigation water over the minimum, there was a decrease in the percentage of protein in the wheat and flour. With maximum irrigation the protein content fell off very sharply. The protein content of all samples grown with normal amounts of irrigation water and less, was remarkably high. That of samples from the plats given maximum irrigation was sufficient to give them unquestioned standing among high-protein wheats.

#### THE WORK OF 1914, 1915 AND 1916 AS A WHOLE.

In Table XV are presented the averaged field and analytical data for the years 1914, 1915 and 1916.

In connection with the study of this table, the conditions of growth for the three-year period should be clearly in mind. The soils which grew these crops, like that which grew the crop of 1913, had been substantially enriched with nitrogen-containing organic matter and through the activity of nitrifying organisms soil nitrogen had been put in available form in substantial amounts for the wheat plants.

Large increases of water over normal amounts increased the average yield of straw in each series but not the average yield of grain. In the increased yield of Sonora for this period over the first three years with corresponding amounts of water, there is substantial additional proof for the claim made elsewhere by Superintendent Welch that the duty of water is increased substantially with an increase in the soil's content of organic matter. The maximum weight of grain was reached in each series with normal irrigation. In each of the three series grain of remarkably high protein content was produced with normal applications of water and less. Protein in the grain from each series fell off sharply with an increase in irrigation water over the normal, but with the possible exception of Sonora not to an extent sufficient to rule the samples grown with maximum irrigation out of the high-protein class. With the possible exception of Sonora grown with maximum irrigation, the high protein and gluten content of the flours would insure for them a high place in the estimation of bakers who are accustomed to the handling of strong wheat flours. The mineral requirements of the wheat plants in so far as the grain is concerned seem to have been satisfied with the minimum application of water.

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Table XV. *Averages for field and analytical data, crops of 1914, 1915 and 1916.*

Plat	Number	Labo- ratory	Variety	Wheat										Flour												
				Total		Yields		Weight		Crude protein				P <sub>2</sub> O <sub>5</sub>		K <sub>2</sub> O		Mois- ture		Ash		Crude protein		Gluten		
				irri- gation, feet	acre, bu.	Grain per acre, bu.	Straw per acre, tons	per 1000 bushels, lbs.	per acre, bu.	per cent.	Mois- ture per cent.	on dry basis per cent.	Ash per cent.	in grain per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	
—	1		Minn. Blue- stem, Minn.	206†	21.00	1.19	26.91	53.8	10.12	17.69	19.69	1.87	1.03	.55	12.56	.57	13.97	49.85	15.91	—	—	—	—	—	—	—
4	1		No. 169	534	27.43	1.67	27.46	53.7	9.72	17.73	19.64	1.97	1.07	.57	12.89	.57	14.24	51.03	16.64	—	—	—	—	—	—	—
7	10		"	1,029	41.74	2.10	35.15	58.3	9.76	18.46	18.24	1.92	1.05	.53	12.61	.57	12.84	43.66	13.89	—	—	—	—	—	—	—
10	10		"	2,135	39.82	2.73	33.47	56.3	10.24	13.81	15.38	1.90	1.04	.52	12.76	.56	11.20	36.76	13.51	—	—	—	—	—	—	—
—	2		Glyndon	—	—	—	25.53*	—	10.28	12.71	14.16	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5	2		Fife, Minn.	164†	25.51	1.34	25.55	55.0	9.85	18.07	20.05	1.82	.95	.53	12.23	.53	14.19	51.80	16.69	—	—	—	—	—	—	—
8	2		No. 163	493	35.24	1.71	25.92	55.7	10.23	17.67	19.68	1.85	1.05	.54	12.62	.53	14.30	53.33	17.23	—	—	—	—	—	—	—
11	8		"	1,121	46.57	2.21	32.68	58.7	10.42	16.48	18.37	1.96	1.06	.51	12.62	.51	13.46	46.60	15.15	—	—	—	—	—	—	—
11	11		"	2,287	43.80	2.69	33.57	56.3	10.59	13.53	15.14	1.93	1.06	.53	12.40	.48	11.50	37.25	12.48	—	—	—	—	—	—	—
3	3		Sonora	1,737	19.95	1.05	26.97	58.3	10.78	16.91	18.96	1.84	.98	.50	12.15	.51	13.10	45.33	16.01	—	—	—	—	—	—	—
6	9		"	910	31.04	1.55	28.61	55.3	9.91	15.39	17.09	1.88	.98	.51	12.33	.47	11.91	40.05	14.62	—	—	—	—	—	—	—
9	9		"	1,052	37.40	1.74	32.52	57.7	10.39	14.78	16.50	1.93	1.02	.51	12.42	.52	11.76	42.23	15.53	—	—	—	—	—	—	—
12	12		"	2,735	38.65	2.03	31.73	58.5	10.48	11.49	12.82	1.95	1.04	.56	12.41	.45	9.92	31.23	11.45	—	—	—	—	—	—	—

\* Original seed grown at University Farm, Minnesota, 1908.  
† Irrigated in 1915 only.

\* Original seed grown at University Farm, Minnesota, 1908.

† Irrigated in 1915 only.

Fig. 7 presents graphically the correlation of irrigation and protein data for these three years.

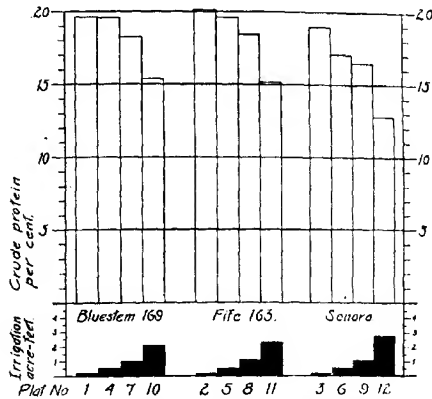


Fig. 7. Crude protein of wheats grown for three years with varying amounts of irrigation water. Drawn from data presented in Table XV.

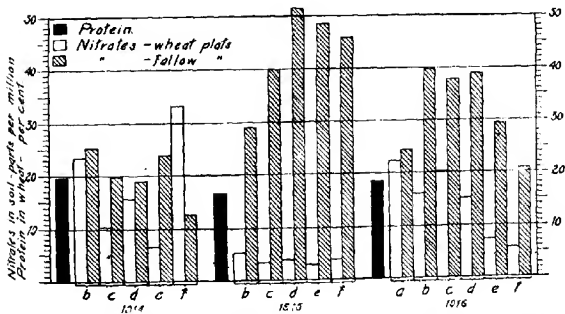


Fig. 8. Protein in Minnesota Bluestem (Minn. 169) from plots given normal irrigation in 1914, 1915 and 1916 and the average amounts of soil nitrates in the same plots to a depth of three feet by periods during the same years: a period, May 16 to 31 inclusive; b period, June 1 to 15 inclusive; c period, June 16 to 30 inclusive; d period, July 1 to 15 inclusive; e period, July 16 to 31 inclusive; and f period, August 1 to 19 inclusive.



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In Figs. 8 and 9 the nitrate data averaged for the first three feet from determinations made during 15 and 16 day periods in May, June, July and in August and the protein data for the plats given normal and maximum irrigation are shown for correlation.

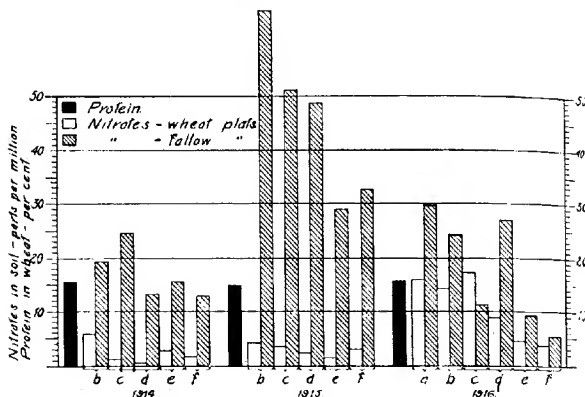


Fig. 9. Protein in Minnesota Bluestem (Minn. 169) from plats given maximum irrigation in 1914, 1915 and 1916 and the average amounts of soil nitrates in the same plats to a depth of three feet by periods during the same year.

#### THE SEVEN YEARS' WORK IN REVIEW.

The outstanding facts in the field and analytical data covered by the entire time of this investigation may now be summarized for correlation wherever possible.

Climate, of course, imposed certain uncontrollable conditions of growth throughout the investigation. The more outstanding ones were a low humidity, high percentage of sunshine and comparatively low temperatures during the growing seasons. These conditions, however, were so nearly uniform year after year as to merit no further consideration in this connection. The controllable conditions of growth were those of the soil. The conditions imposed during the first three years' work were those of a soil rich in the essential mineral elements of plant food but low in nitrogen and varied between rather wide limits in its content of moisture.

From seed fairly high in protein at the beginning of the work in 1910, the harvested grain from all plats in each series reached a very

low level of protein in the crop of 1912. Substantial variations in amounts of irrigation water were without marked effect in producing variations in the protein content of the harvested grain and flour ground from it. The irrigation data for 1911 and 1912, averaged from determinations made during 15 and 16 day periods in June, July and from those made in early August, graphically presented in Fig. 10, lend little support to the notion that there was a concentration of nitrates in zones beyond the feeding range of the wheat plants. The only tenable explanation of the low level of protein reached lies, we believe, in the inadequacy of the soil's content of available nitrogen to permit of maximum yields and maximum elaboration and storage of protein.

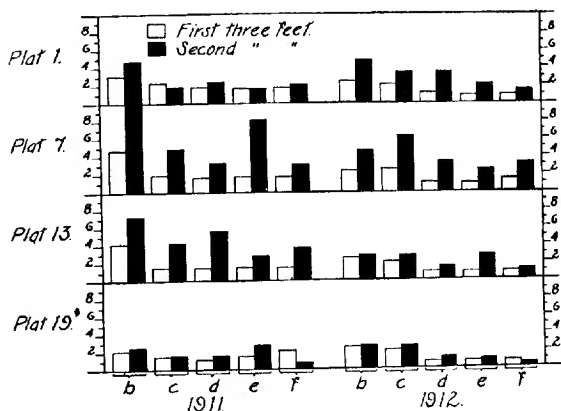


Fig. 10. NO<sub>3</sub> in parts per million on dry soil averaged for periods of 15 and 16 days in June, July and August for the first three feet and the second three feet of plots 1, 7, 13 and 19, years 1911 and 1912.

In 1913 the soil conditions for growth were modified. The conditions that year made for a superabundance of available nitrate in the wheat plots and the wheat profited accordingly as shown by the enormous increase in protein in the product of each plot that year. In each series the plot given maximum irrigation produced grain lowest in protein. For an explanation of this occurrence one might with reason look for a lessened activity on the part of nitrifying organisms in the presence of a greater amount of soil moisture or in the leaching effect of the larger applications of water operating to remove the nitrates beyond



the feeding range of the plant roots. An examination of the nitrate data for that year, however, lends no support whatever to the first hypothesis and very little if any to the second. It may be that the explanation lies in a decreased transpiration of the wheat plants because of excessive amounts of soil moisture. The substantially greater amounts of protein in the grain of all plats over that of the original seed and over that grown from corresponding plats of the preceding year answer in the negative the question raised at the beginning of the work relative to cumulative and permanent effects of large amounts of water on the protein content of wheat. It is perfectly apparent that however low wheat may go in its content of protein because of adverse conditions of growth or because of conditions which do not favour the elaboration of protein, it responds immediately to favourable conditions of growth and a soil rich in available nitrogen by elaboration and storage of maximum quantities of protein.

In 1914 Minnesota Bluestem and Glyndon Fife were substituted for Palouse Bluestem and Little Club. For that year and the next two years, if we may judge from the nitrate data for those years, conditions of growth were such as to insure for the growing wheat plants a liberal supply of available soil nitrogen, at least during the early growing periods. With normal irrigation and less, remarkably high percentages of protein in the harvested grain were shown each year. In each series maximum irrigation produced grain of lowest protein content but always grain sufficiently rich in protein to insure for it a high standing. In a final attempt to establish a definite and fundamental reason for this sharp decline in protein from the application of the maximum amounts of water in soils rich in nitrate nitrogen, the nitrate data for the three years were very critically examined. The data for 1914 and 1916 support, to some extent, the notion that heavy applications of water tend to remove nitrate nitrogen from the feeding range of plant roots. Fig. 11 is based upon the nitrate data for these two years averaged for the first three and the second three feet for whatever determinations were made in 15 and 16 day periods in May, June, July and in early August. Unmistakable proof, however, of the leaching effect of the irrigation water upon the nitrates in the surface feet of soil to the detriment of the growing plants is not in our judgment apparent. A fundamental reason for the falling away of protein when excessive applications of water are given under the conditions noted has not yet been definitely established.

At the end of seven years of growth with an average annual appli-

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cation of irrigation water exceeding 2-3/4 acre-feet, the Sonora was decidedly richer in protein than the original seed. Minnesota Bluestem and Glyndon Fife with normal irrigation developed greater weight and at the same time substantially greater amounts of protein than were contained in the original Minnesota-grown seed. Moreover, the maximum irrigation given these two varieties failed to lower the protein content below that of the original seed and to reduce the average protein for the three years below the average for the same varieties grown the same years at University Farm, Minnesota<sup>1</sup>.

#### CONCLUSIONS.

Since this investigation was conducted under field conditions that are identical with those which confront the settler on the raw lands of our irrigation projects on the Snake River plains, the results secured and our field observations in connection with them warrant several very definite conclusions regarding the possibility of growing a better quality of wheat for milling purposes with irrigation.

1. The general run of wheat grown with irrigation in that part of the intermountain section represented by the Snake River plains is soft and starchy and unquestionably low in protein, therefore, of relatively low value for flour-making purposes.

2. Growers and millers are not right, however, in assuming that low-protein wheat necessarily results from the practice of irrigation. As a matter of fact irrigation is not the controlling factor in determining what shall be the protein content of the harvested grain.

3. In the course of their development irrigation projects produce and market large amounts of wheat from practically raw sagebrush soils—soils whose content of available nitrogen is always low. Regardless of the amount of irrigation water used, wheats from soils of that kind are invariably low in protein.

4. A much better quality of grain is possible as soon as grain is brought into rotation with alfalfa or red clover. The sod of these legumes turned under and the activity of nitrifying organisms provide for the growing wheat plants a substantially greater supply of available nitrogen. Protein elaboration is stimulated somewhat in proportion. Carelessness in the use of irrigation water may off-set to some extent, however, the advantage of otherwise favourable soil conditions for maximum protein elaboration. The climate of the irrigated sections is favourable. The essential soil conditions for high protein wheat are

<sup>1</sup> Bulletin No. 103, Idaho Experiment Station.

easily within the control of the irrigation farmer. Fortunately soil conditions which favour maximum protein elaboration are also those which favour maximum production.

5. However "deteriorated" in quality a really good variety of milling wheat may be from growth with irrigation on soils depleted of available nitrogen, seed from it will respond with the production of maximum amounts of protein for the variety if given the favourable conditions of growth indicated in the preceding paragraph. There is nothing to be gained by the irrigation farmer by importing seed of that variety from distant localities.

6. There is much to be gained, however, by irrigation farmers from the more rigid selection of varieties on the basis of well-recognized milling value. The notion that low-protein wheat and irrigation practice are inseparably linked is largely responsible for the carelessness so frequently shown by irrigation farmers in the selection of varieties. Bushel for bushel the hard red spring wheats at their best command a somewhat higher price, and, when used properly, can be made to go much further than the soft starchy varieties in feeding a hungry world. In the light of this investigation we would not question the ability of the careful irrigation farmer to grow the highest quality of the hard red spring wheats. In the absence of positive proof that the hard red spring varieties will hold their own from the standpoint of production in comparison with the better classes of white wheats, always popular with the irrigation farmer, we do not wish at this time to urge their introduction and growth except for trial. In this connection it is well to emphasize the fact that the white wheats will also respond to favourable conditions for protein elaboration. White wheats rich in protein, we venture, will command a premium among millers in the intermountain states if grown in sufficiently large quantities to command their attention.

7. Unquestionably there are large amounts of high-protein wheats being grown now on the older irrigation projects under conditions we have outlined above. It is doubtful if the growers realize on them as they should because they are lost in the larger amounts of low-protein wheats grown on soils not yet brought into rotation with alfalfa, red clover, or other legumes. When the requirements for high-protein wheats are more generally understood, and the irrigation projects reach that point in their development where there is no more raw sagebrush land given over to wheat production, and undesirable milling varieties have been eliminated, this matter will right itself. In the meantime

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growers on any project who really desire to grow high-protein wheat might with profit to themselves form an organization that would force the attention of millers to their product.

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# 'STUDIES OF A SCOTTISH DRIFT SOIL.

## PART II.

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### THE ABSORPTIVE POWER OF THE SOIL AND ITS MECHANICAL FRACTIONS.

THE problems connected with absorption by soils have been studied by many investigators for well-nigh a century, but in spite of this, comparatively little is known even now regarding this important phenomenon. Its importance cannot be too strongly emphasised when we consider its bearing on soil fertility in general, and in particular on the part played by fertilisers.

It is still a matter of dispute whether soil absorption is a physical or a chemical phenomenon or partly one and partly the other. The question of the soil constituents to which absorption is chiefly to be attributed is also undecided. Some workers lay special emphasis on the amount of surface exposed by the absorbing material, while others lay stress on its origin, constitution and mass.

The literature of the subject has recently been reviewed by Prescott (1)\*, to whose résumé the reader is referred.

Attempts have been made from time to time to make use of absorption phenomena as indicators as to fertility and manurial requirements, but the difficulty has been to get a good basis for comparison of different soils.

Soils differ greatly in their mechanical and chemical composition and in their content of organic matter, and all these factors may profoundly affect absorption.

Other things being equal, a soil composed largely of "fine silt" and "clay" would, according to most investigators, have a greater absorptive power than one composed chiefly of coarse materials. Conclusions,

\* Publication of this paper was delayed on account of the war, and since it was drafted a more complete résumé of the literature by Prescott has appeared in this Journal. A review of the literature has therefore been omitted.



therefore, derived only from comparing absorptions by complete soils might be quite misleading.

The object in this investigation, in addition to determining the absorption of the soil as a whole, is to determine the absorptive power of the various fractions obtained by mechanical analysis.

It is hoped in this way to obtain useful information as to the part played in the absorption by the various soil fractions and to arrive at a sound basis for comparing the absorptive power of this soil with others in this district and elsewhere.

The soil with which our investigations were made has already been described in Part I of this paper(2). It has these characteristics in particular:

1. It is a glacial drift soil derived from granitic rocks and its constituents are still in a comparatively undecomposed state. According to van Bemmelen the production of the colloids on which absorption depends is largely a question of decomposition.

2. It contains no carbonate of lime. Calcium carbonate has been persistently associated in this country with absorption and the interchange of bases in soils, as if it were a necessary factor, though Way as early as 1850 had shown that this is not the case.

3. The clay fraction is comparatively small—see Mechanical Analysis, Table I, Part I. It is to this fraction that most of the absorptive power is usually ascribed.

4. It is fairly rich in organic matter, containing about 9 % as determined by ignition. This is generally considered to play a considerable part in soil absorption.

The first difficulty met with in carrying out this investigation was the separation of the soil into fractions without producing any alteration in their chemical nature and absorptive power.

The ordinary British method of mechanical analysis involving the use of weak acid and ammonia could not be followed, since it seems obvious that the action of such reagents would alter the absorptive power of the soil particles, so an attempt was made at a separation by means of water alone.

As a preliminary trial, 10 gram samples were treated according to the sedimentation method as adopted by the Agricultural Education Association (3) (the ordinary British method), except that treatment with dilute hydrochloric acid and ammonia was omitted.

The results did not accord very closely with those from the ordinary

method with use of acid and ammonia, the clay being much less and the coarser fractions greater, indicating, as was to be expected, an incomplete breaking down of the compound particles.

The operation was repeated with these differences: (a) The samples were soaked a couple of days in distilled water and thoroughly rubbed up with a rubber pestle before the fractionation was commenced. (b) They were shaken in bottles on a mechanical shaker for an hour between periods of settling. The results obtained in this way agree much better with those from the ordinary method, but the amount of clay obtained still fell short of the total present.

Table I. *Mechanical Analysis.*

	1		2		3	
	Analysis using distilled water in separation		Analysis using distilled water and subjecting soil to thorough pestling		Analysis according to method of Agricultural Education Association	
	At 100° C.	After ign.	At 100° C.	After ign.	At 100° C.	After ign.
Fine gravel ...	10.58	10.46	10.19	10.07	10.09	9.93
Coarse sand ...	34.79	33.59	31.41	31.03	30.08	29.73
Fine sand...	32.25	29.41	26.54	26.01	26.20	25.80
Silt ...	12.68	9.89	14.72	12.44	14.18	12.47
Fine silt ...	7.98	5.76	9.64	7.07	9.62	7.63
Clay ...	0.90	0.43	6.53	3.09	8.88	3.80
Total ...	99.18	89.54	99.03	89.71	99.05	89.36
Loss on ignition...	—	9.64	—	9.32	—	9.69
Dissolved and loss (by difference)...	—	0.82	—	0.97	—	0.95

Table I shows the different results obtained by modifying the method of analysis as described above.

No. 1 is the mechanical analysis using distilled water, and without previous treatment with dilute acid and alkali.

No. 2 the same with additional soaking, shaking and pestling with a rubber pestle.

No. 3 the analysis by the ordinary British method with dilute acid and ammonia. Duplicate samples agreed closely except in the coarsest fractions.

Since the shaking and pestling in No. 2 and the reagents in No. 3 bring an undue proportion of the humus into the finest fractions, it is only the columns after ignition that are strictly comparable.

Hall(4), in comparing methods of mechanical analysis obtained similar results. Attempts at a separation by mechanical means alone, failed to remove all the clay from the coarser fractions. From his

experiments, he concluded that treatment of the soil with dilute acid before commencing analysis does not dissolve any appreciable amount of the mineral matter except  $\text{CaCO}_3$ , and that all it does is to resolve completely the temporary aggregates.

According to Dumont (5), the mineral particles of the soil are covered with a humus-clay coating very difficult to remove. But whether it is as a coating to the larger particles or in the form of aggregates the tenacity with which the clay is held may be judged from a comparison of the results in Table I.

For the purpose of this investigation fairly large quantities of each fraction were required, so the mechanical method described above was now applied on a large scale. 1000 grams of soil passing the 3 mm. sieve were soaked, pestled and shaken as before and a mechanical analysis (corresponding to No. 2, Table I) carried out, using vessels suitable for the increased quantity of material.

It was found that 40 to 50 decantations were necessary to remove the clay, and even then the supernatant liquid was not perfectly clear, and the difficulty arose of removing the small amount of clay from the very large volume of water. Settling was slow and incomplete, and it was obviously inadmissible to employ any flocculating agent; filtration was useless as the fine particles quickly clogged up the pores; evaporation was undesirable both on account of the time required and because of the danger of altering the properties of the clay; no suitable centrifugal machine was at hand so at the suggestion of one of us an ordinary cream separator was tried and this proved very successful.

It was found, if the inlet were regulated to allow only a small stream to enter, and if a fairly high speed were kept up (8000-10,000 revolutions of the bowl per minute), that an almost perfect separation was effected.

The plates of the separator bowl which at the end of a milk separation are coated with a slime of impurities removed from the milk, retained the clay. The bowl was removed and dried in an air oven at a low temperature, and when dry, the clay was easily removed from the plates.

The other fractions were obtained without difficulty, and the sizes of their particles checked with the microscope.

THE PRESENCE OF ORGANIC MATTER IN THE FRACTIONS  
AND ITS DISTRIBUTION.

There was present in the soil examined, a considerable amount of organic matter which in the mechanical analysis became distributed among the fractions. That the organic matter plays some part in absorption by soils has long been recognised, but its exact share is very difficult to determine, since removal of the humus by ignition or by solvents would alter the properties of the mineral particles and colloids.

Hall and Gimingham (6), from experiments with peat, concluded that its influence was comparable to that of clay. This, however, must vary according to the nature and stage of decomposition of the humus, and would differ in different samples and in different fractions of the same sample. To enable us to make, if possible, some allowance for its influence on the absorptive power of the fractions, and to facilitate comparisons with future work on other soils, humus was estimated in each fraction separately. This was carried out in two ways: (a) loss on ignition was determined, (b) the carbon in the various samples was determined by a modification of the chromic acid method (Cameron and Brazeale (7)), and the organic matter calculated on the assumption that soil organic matter contains 58 % of carbon.

Table II. *Organic Matter in the Soil and its Fractions.*

Fraction	Chromic Acid Method (Cameron and Brazeale)	
	per cent.	Loss on ignition per cent.
Fine gravel ... ..	1.04	1.38
Coarse sand ... ..	0.92	1.07
Fine sand ... ..	0.98	1.36
Silt ... ..	9.52	11.81
Fine silt ... ..	20.76	28.52
Clay ... ..	24.52	34.59
Original soil ... ..	6.11	9.69

An examination of the soil showed the organic matter to be well decomposed. No fresh vegetable remains were to be seen and the humus appeared to be well decayed.

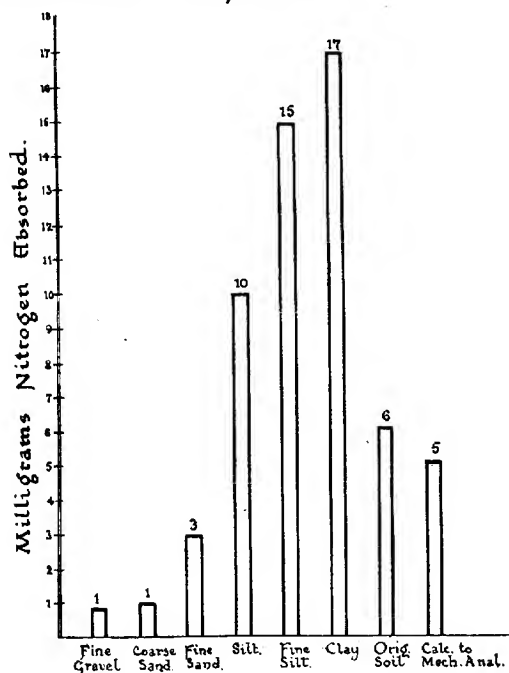
The amount in the original soil (over 9 % as shown by ignition) is about normal for soil of the district, and the process of mechanical analysis naturally brought the bulk of the organic matter into the finest fractions.

The amounts as shown by loss on ignition are considerably greater than by the Chromic Acid Method, and this is doubtless due to the breaking up of hydrated compounds by ignition.

ABSORPTIVE POWER FOR AMMONIA OF THE SOIL  
AND ITS FRACTIONS.

The method adopted for determining the absorptive power was to shake up small quantities of the soil and its fractions with a certain volume of a weak solution of ammonium sulphate. After contact for

**Absorption by 10 gram portions of Soil  
fractions from a solution of ~~~~~  
Ammonium Sulphate.**



a period long enough to make sure equilibrium had been attained, the solution was separated by means of filtration and the amount of ammonia removed determined by distillation with magnesia. The results have

been expressed throughout this paper as grams nitrogen removed by 10 grams of the soil or of the soil fractions from 50 c.c. of solution.

The solution used was obtained by dissolving 5 grams ammonium sulphate in distilled water and making up to 1 litre. 50 c.c. of this solution was added to 10 gram portions of the air dried soil fractions in stoppered bottles, and these were shaken at intervals for 24 hours.

After settling to allow solid materials to fall to the bottom, the supernatant liquid was poured off and filtered through one thickness of ordinary Swedish filter paper. The filtrate was analysed for nitrogen by distillation with magnesia using N/10 NaOH and N/10  $\text{H}_2\text{SO}_4$ .

By taking 20 c.c. at a time for an estimation, the determinations were carried out in duplicate.

Filter paper has a small absorptive capacity but a blank was carried out on the original ammonium sulphate solution, and this was first passed through a filter paper. Again, as it was not the object of this investigation to get an accurate mathematical expression, but to get a general workable idea of the absorptive power of the soil itself, and of its various fractions, with a view to comparison with other soils, no account was taken of temperature, but as the experiments were all carried out at ordinary laboratory temperature which did not vary much, any differences due to this cause could only have been very small.

Table III. *Absorption by Soil and its Fractions.*

Fraction			Absorption by 10 grms. of material from 50 c.c. solution of ammonium sulphate. (grms. nitrogen)
Fine gravel	...	...	-001
Coarse sand	...	...	-001
Fine sand	...	...	-003
Silt	...	...	-010
Fine silt	...	...	-015
Clay	...	...	-017
Original soil	...	...	-006

Table III gives the absorptive power as grams of nitrogen absorbed by 10 gram portions of the soil and its fractions.

Duplicates were found to vary to an extent not greater than .2 c.c. N/10 NaOH, equal to .00028 gm. N. This variation was due probably to the separation not being perfect and the samples not being perfectly uniform, but as it does not affect the third decimal place, it is not important.

The samples could not be completely dried before being used in the

absorption experiments, as that might have interfered with colloid matter which they contained, and hence with their absorptive capacity. As the different fractions contained different amounts of moisture separate estimations of the moisture were made by drying portions of 10 grams at 100° C.—the results in Table III being based on the dry weight.

The following conclusions may be drawn from Table III:

1. The soil itself before separation into fractions has a fairly high absorptive power for ammonia from a solution of ammonium sulphate.
2. There is a very considerable absorption by each fraction beginning with "fine sand."
3. "Silt" and "fine silt" have a very high absorptive power—approaching that of "clay." This may be partly due to the organic matter, but the fact stands out clearly—that these fractions can play an important part in soil absorption.
4. The absorptive power of "clay" is highest, but is not so high compared with that of "silt" and "fine silt" as might have been expected, considering the enormously greater surface.

#### DISTRIBUTION OF THE ABSORPTIVE POWER AMONG THE SOIL FRACTIONS.

Although the "clay" has the highest absorptive power its actual share in the total absorption by soil depends on the amount present. In Craibstone soil, as we have seen, there is but a small amount of "clay," especially if the weight after ignition is taken.

To compare the shares of the different fractions in the total absorption, the absorption of each fraction must be multiplied by the percentage of the fraction which the soil contains. This has been calculated both from the percentages before and after ignition. Table IV (A) shows the absorption calculated on the mechanical analysis by distilled water (Table I, No. 2). Table IV (B) shows the absorption calculated on the mechanical analysis by the ordinary British method.

It will be seen from these tables that "fine silt" and "silt" take a very large part in the absorption by this particular soil and even the "fine sand" has a considerable influence.

This may of course be largely due to the organic matter in these fractions, but it at any rate shows that a soil which contains but little "clay" may from its other fractions have a considerable absorptive power.

The presence of organic matter and the other limitations in these determinations make it impossible to ascertain whether the absorptive power is proportional to the amount of surface, but the evidence seems to indicate that the "silt" and "fine silt" have at any rate as great an absorptive power in this soil as the "clay."

Table IV (A).

*Distribution of the Absorptive Power among the Fractions  
of Craibstone Soil.*

(Calculated on the Mechanical Analysis by distilled water alone (Table I, No. 2).)

Fraction	Absorption by 10 grms. of fraction (grms. nitrogen)	Percentage of fraction in soil (before ignition)	Percentage of fraction in soil (after ignition)	Absorption × percentage (before igni- tion)	Absorption × percentage (after igni- tion)
Fine gravel ...	·001	10·19	10·07	·01	·01
Coarse sand ...	·001	31·41	31·03	·03	·03
Fine sand ...	·003	26·54	26·01	·08	·08
Silt ...	·010	14·72	12·44	·15	·12
Fine silt ...	·015	9·64	7·07	·14	·11
Clay ...	·017	6·53	3·09	·11	·05
Total ...	—	—	—	·52	·40

Table IV (B).

*Distribution of the Absorptive Power among the Fractions  
of Craibstone Soil.*

(Calculated on the Mechanical Analysis by the ordinary British method (Table I, No. 3).)

Fraction	Absorption by 10 grms. of fraction (grms. nitrogen)	Percentage of fraction in soil (before ignition)	Percentage of fraction in soil (after ignition)	Absorption × percentage (before igni- tion)	Absorption × percentage (after igni- tion)
Fine gravel ...	·001	10·09	9·93	·01	·01
Coarse sand ...	·001	30·08	29·73	·03	·03
Fine sand ...	·003	26·20	25·80	·08	·08
Silt ...	·010	14·18	12·47	·14	·12
Fine silt ...	·015	9·62	7·03	·14	·11
Clay ...	·017	8·88	3·80	·15	·06
Total ...	—	—	—	·55	·41

There are probably other factors than area of surface determining the amount of absorption. It has already been shown, in Part I, that the different fractions differ greatly in composition, so it is at least possible that differences in composition of the various fractions have some influence on the absorptive power.



## SUMMARY.

1. Craibstone soil—a glacial drift soil which has not undergone very profound weathering and is free from calcium carbonate—has a considerable absorptive power for ammonia from a solution of sulphate of ammonia.

2. It was found possible to make a mechanical analysis of a large quantity of this soil without the use of acid and alkali, and although the separation into fractions was by no means perfect, a very fair comparison was obtained of the absorptive capacities of the different fractions.

3. The absorptive power per unit weight of the fractions, as would be naturally expected, increases with the decrease in size of the particles, reaching a maximum in the case of "clay."

4. "Fine silt" and "silt" have also a high absorptive power. This may be partly due to the presence of organic matter, but allowing for that, these fractions have a high power of absorption.

5. It was not the object of these experiments to draw any detailed conclusions as to the relation between surface and absorptive power, but it seems probable, from the results obtained, that the absorptive power is not determined by surface alone, and that the chemical composition of the fractions has an influence on the absorptive power.

6. The distribution of the absorptive power among the various fractions showed that in this particular soil with its comparatively small amount of "clay," the "fine silt" and the "silt" take a large share in the total absorption.

7. By thus dividing soil samples into fractions and comparing the absorptive power of the fractions, surface differences are largely eliminated, and it may be possible to throw some light on the influence of differences of chemical nature and geological origin on absorptive power.

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# STUDIES OF A SCOTTISH DRIFT SOIL.

## PART III.

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### THE ABSORPTIVE POWER OF POWDERED GRANITE AND A COMPARISON WITH CRAIBSTONE SOIL.

It has been shown in Part II that a glacial drift soil in a comparatively unweathered condition has a considerable power of absorption for ammonia, although it has sometimes been held that it is the weathered material in soils that is responsible for the absorptive power. Glacial drift, as exemplified in the Craibstone soil, however, though its weathering is geologically recent compared with that of many English soils, has been subjected to age-long weathering since the glacial period, and in the process of soil formation a certain amount of weathering with the resultant decomposition has necessarily taken place. Craibstone soil has also been shown (Table II, Part II) to contain a fairly large percentage of organic matter and it might be contended that the absorptive power was chiefly due to either or both of these factors.

To prove or disprove this directly would be a very difficult matter, but it is possible to show whether a comparable substance which has not undergone weathering to any appreciable extent and is free from organic matter has a similar absorptive power. This is by no means a new line of inquiry. In an attempt to determine the substance in soils on which absorption depends, Way (1) turned his attention "to the compound silicates present in clay and derived from the granitic rocks to which clay owes its origin. Fragments of such rocks are found in clay. e.g. Felspar—double silicate of alumina and potash; albite—a double silicate of alumina and soda; also a similar double silicate of alumina and lime. These different natural silicates finely powdered were digested in a solution of  $\text{NH}_4\text{Cl}$  but none of them possessed the power of com-

binning with its ammonia. It is not, therefore, to the undecomposed remains of the granitic rocks that the absorptive power of clay is to be referred."

Since Way's time, however, several investigators have shown that when salt solutions come in contact with certain minerals, a portion of the base is removed from solution. Sullivan(2), who has carried out a series of investigations on this subject with special reference to geologic phenomena writes, "With this in view, some of the changes that take place at ordinary temperature when water solutions are brought into contact with rock-forming minerals have been examined. The result has been in a word to make it apparent that the chemical reaction between silicates and salt solutions is a very general phenomenon, taking place to a decided extent immediately upon contact, and that the outcome is mainly an exchange of bases in chemically equivalent quantities between solid and solution; the metal of the dissolved salt is precipitated and an equivalent quantity of silicate is decomposed and its bases enter the solution. Salt solutions as decomposing agents are much more active than pure water and are comparable with acids in this respect."

From chemical analysis of mechanical separates (Part I of this paper(3)) from a mineralogical examination, and from a consideration of its origin it has been concluded that Craibstone soil contains a considerable proportion of little-weathered material. As it was impossible to separate the weathered from the unweathered and to remove the organic matter, a comparable substance unweathered and free from organic matter was sought for, and since the soil was derived from granitic material, granite was chosen.

The material used was obtained from Dancing Cairns quarries near Aberdeen and is a typical granite containing quartz, orthoclase, oligoclase, black mica, and white mica. It consisted of powder ground from granite rubble at the quarries by a factory which prepares artificial paving stones from granite dust and cement. The sample used was therefore a roughly ground powder prepared by mechanical means from granite.

It consisted of material of all sizes from pieces with a diameter of three to four millimetres down to the finest dust. For comparison with the soil, this was subjected to a mechanical analysis with distilled water, as described in Part II of this paper; the fractions obtained corresponding to "fine gravel" (3-1 mm.), "coarse sand" (1-2 mm.), "fine sand" (.2-.04 mm.), "silt" (.04-.01 mm.), "fine silt" (.01-.002 mm.) and "clay" (below .002 mm.).

## ABSORPTION OF AMMONIA BY POWDERED GRANITE.

The absorption of ammonia from a solution of ammonium sulphate was determined for these fractions as in the case of the corresponding fractions of Craibstone soil (see Part II of this paper).

There were again limitations as regards perfect separation of the fractions and method of estimating the absorption though the absence of organic matter and other material binding the particles together rendered the separation much simpler than in the case of soil. The final results are expressed only to the third decimal place.

Table I. *Absorption by Powdered Granite.*

Fraction	Absorption by 10 grms. of material from 50 c.c. of solution of ammonium sulphate (grms. nitrogen)
Fine gravel...	—
Coarse sand ...	·001
Fine sand ...	·002
Silt ...	·004
Fine silt ...	·011
Clay ...	·021

From these results it is evident that powdered granite has a considerable power of absorbing ammonia from a solution of ammonium sulphate, and as would naturally be expected this power is by far the greatest in the finest fractions.

A comparison of the relative surfaces exposed by the different fractions is interesting in this connection.

If it is assumed that the particles are all spherical and have a specific gravity of 2·65 and if the mean diameter of the particles in each fraction be taken, the surface of any weight of a fraction can be calculated from the following formula.

$$\text{Surface} = \frac{\text{wt.} \times 4\pi r^2}{\text{spec. grav.} \times \frac{4}{3}\pi r^3} = \frac{\text{wt.} \times 3}{\text{spec. grav.} \times r}$$

It is impossible to draw any conclusions as to the connection between surface and absorptive power, for the different fractions almost certainly differ in chemical composition, and also no allowance was made for the falling off in absorption as ammonia was removed and the solution became weaker.

The actual particles are not uniform spheres, but are of infinite variability and the surfaces are much greater than shown. Besides, as

Sullivan points out, the surface actually exposed to a salt solution even in the case of a fresh rock *in situ*, is perhaps greater than is apparent, and in the material under consideration, the fractures caused by the grinding must have further increased the surface.

Table II.

*Absorption and Theoretical Surface of Granite Fractions.*

Fraction	Surface per 10 grms. (sq. cms.)	Absorption per 10 grms. from solution of ammonium sulphate (grms. nitrogen)
Fine gravel ...	113	—
Coarse sand ...	377	·001
Fine sand ...	1887	·002
Silt ...	9057	·004
Fine silt ...	37,736	·011
Clay ...	226,415	·021

It may however be assumed that the surface varies inversely as the mean diameter, as in the case of regular figures. If we calculate on this assumption we arrive at the figures shown in Table III.

Table III.

	Mean diameter (mm.)	Proportion	Inverse	Actual absorption proportion found by experiment
Coarse sand ...	·7	700	1	1
Fine sand ...	·12	120	6	2
Silt ...	·025	25	28	4
Fine silt ...	·006	6	116	11
Clay ...	·001	1	700	21

In Table III the column headed "Inverse" shows approximately the inverse proportions of the mean diameters, and it will be seen that the actual absorption found in the case of the different fractions is not even approximately proportional to these inverse proportions. For instance the "fine silt" and "clay" have mean diameters which bear the ratio to one another of approximately 6 to 1. The "clay" should therefore have about six times the surface of the "fine silt," but its absorptive power is only about twice as great as that found for the "fine silt." Somewhat similar results are found in the other cases. The evidence, therefore, so far as it goes, indicates that the absorption does not vary proportionally to the surface, though as the surface becomes greater the absorption becomes greater, but at a much lower rate.

COMPARISON OF THE ABSORPTIVE POWER OF THE SOIL  
AND GRANITE FRACTIONS.

In comparing the soil and the granite fractions we must take account of the following differences:

1. The soil contains humus and the granite does not. The granite has on that account, however, a greater mineral surface.
2. Through weathering agencies the soil constituents have undergone some decomposition while the granite may be taken as almost unweathered.
3. In the processes of weathering and grinding, and also in the course of mechanical analysis, the various fractions of soil and granite have to some extent become sorted out into material of different chemical composition.
4. The soil constituents may have already absorbed a certain amount of ammonia before the sample was taken from the field. Bearing these differences in mind, we give the comparison in Table IV.

Table IV.

*Comparison of the Absorptive Power of Soil and  
Granite Fractions.*

Fraction	Granite	Soil	% humus in soil (chronic acid method)
Fine gravel... ..	—	-001	1.9
Coarse sand ... ..	-001	-001	9.9
Fine sand ... ..	-002	-003	6.9
Silt ... ..	-004	-010	9.5
Fine silt ... ..	-011	-015	20.7
Clay... ..	-021	-017	24.5

The comparison brings out a general similarity between the absorptions of the soil and the granite fractions.

The fraction of granite corresponding to "clay" has an absorption higher than that of "clay" from Craibstone soil, and weight for weight of mineral matter nearly as high an absorption even supposing organic matter took no part and the whole of the soil absorption was due to the mineral matter.

The absorption by "fine silt," though less than that by the corresponding soil fraction is fairly high, indicating that "fine silt" in soils apart from the organic matter, may play an important part in absorption.

The coarser fractions are much less important and the large difference in the "silts" may be chiefly due to the presence of humus in the soil fraction, though the evidence does not point that way.

With so many unknown and varying factors it is difficult to draw any detailed conclusions from the comparison, but it seems legitimate to conclude that unweathered mineral particles when they occur in soils may take a very considerable part in soil absorption.

#### ABSORPTION AFTER IGNITION.

As Way pointed out in 1852, the power of a soil to combine with ammonia is greatly reduced by burning it. "It would seem the more strongly the soils were burnt, the more completely was their absorptive power destroyed."

Experiments by Way on a clay containing no vegetable matter nor oxide of iron (from a pit 20 feet below the surface) showed a large absorptive power. After heating strongly for two hours in a covered crucible, the absorptive power was sensibly diminished though anything but destroyed. Way also tried the effect of heat on the artificial double silicates which he prepared, and found that after being heated to redness they no longer absorbed ammonia.

Table V. *Comparison of the Absorptive Power after Ignition.*

Fraction	% loss of weight on ignition		Absorption per 10 grms. before ignition (grms. nitrogen)		Absorption per 10 grms. after ignition (grms. nitrogen)		Absorption by equal weights (10 grms.) ignited material (grms. nitrogen)	
	Soil	Granite	Soil	Granite	Soil	Granite	Soil	Granite
Fine gravel ...	1.38	0.48	.001	—	—	—	—	—
Coarse sand ...	1.07	0.66	.001	.001	—	—	—	—
Fine sand ...	1.36	0.86	.003	.002	.001	.001	.001	.001
Silt ...	11.81	1.05	.010	.004	.002	.002	.003	.002
Fine silt ...	28.52	3.01	.015	.011	.004	.006	.006	.006
Clay ...	34.59	6.96	.017	.021	.005	.013	.007	.014

He concluded that this was due to their losing water of combination. "It is only in the state of hydrates that the double silicates possess the property in question, and this again accounts for the fact that the retentive power of clay and soils in general for ammonia was very much diminished and in some cases entirely destroyed after the soils had been heated to redness."

To see if it would throw any light on the share taken by undecomposed mineral matter in absorption by Craibstone soil, the fractions of soil and granite were ignited and the absorptions after ignition compared.

The organic matter in the soil is destroyed by ignition and the absorptive power of the fractions consequently lowered, but if the

absorption due to mineral constituents is of the same nature in both cases, then after ignition equal weights of soil and granite fractions might be expected to show a similar absorptive power.

To compare the absorption of soil and granite after ignition the fractions were ignited over a Bunsen at a low red heat and the absorption determined as before by shaking up with a solution of ammonium sulphate containing 5 gms.  $(\text{NH}_4)_2\text{SO}_4$  per litre.

The chief points brought out by the comparison are

1. The absorptive power of both soil and granite is very much reduced by ignition.
2. The lowering of the absorption is much greater for soil than for granite.
3. Calculating what would be the absorption by equal weights of ignited material, it is found that the soil and granite fractions are very similar except in the case of "clay" which has its absorption very much further reduced for soil than for granite.

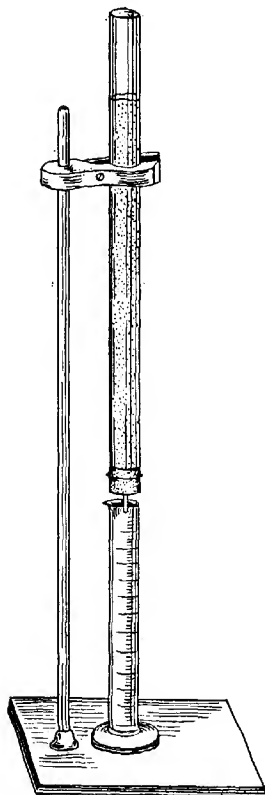
#### RETENTION OF ABSORBED AMMONIA BY UNWEATHERED MATERIAL.

Several investigators have shown that material absorbed by soils is very firmly retained and is not readily removed by water. In regard to this Way(4) writes in 1852 "Whatever may be the form of combination in which ammonia is retained, it is plainly in an insoluble state."

A. Voelcker(5) in 1860 carried out a series of experiments on ammonia retention, and concluded that "In no instance is the ammonia absorbed by soils from solutions of free ammonia or from ammoniacal salts so completely or permanently fixed as to prevent water from washing out appreciable quantities of the ammonia...but the power of soils to remove ammonia from solution is very much greater than their property of yielding it again to water." Retention of absorbed materials probably depends largely on the nature of the soil. In cases where large amounts of organic matter and weathered material are present, these may have the chief share in the retention, and light sandy soils without much humus are generally held to have little power of retaining manures. It has been shown that powdered granite has a considerable absorptive power for ammonia, but this would have little practical value unless accompanied by some power of retention, and to determine whether the absorbed ammonia is readily removed by water, a percolation experiment was carried out.

The finest fractions of granite which have by far the greatest absorptive power could not be used for this purpose on account of the time





PERCOLATOR.

Used for Powdered Granite.

required for the solution to pass through, and also because of its tendency to form channels and not pass evenly. The material used was passed through a sieve with 100 meshes per linear inch, and included all the fractions finer than coarse sand.

The percolator consisted of a glass tube of 2.5 cm. diam. and 100 grms. of the granite occupied a height of about 21 cms. A solution of ammonium sulphate containing 5 grms. per litre was percolated through the column of granite 20 c.c. at a time, and this was continued until the solution came through practically unchanged.

The percolate began to run on the third addition of 20 c.c. of solution and nitrogen was determined as before, by distillation with magnesia, in every 20 c.c. of percolate.

Table VI. *Absorption of Ammonia by Powdered Granite.*

Number of percolate	Grms. nitrogen in 20 c.c. percolate	Grms. nitrogen retained by granite
1	-0004	-0214
2	-0062	-0370
3	-0172	-0416
4	-0199	-0435
5	-0204	-0449
6	-0207	-0460
7	-0210	-0468
8	-0211	-0475
9	-0213	-0480
10	-0214	-0484
11	-0214	-0488
12	-0215	-0491
13	-0196	(-0513)

It will be seen from the table that the ammonia was almost totally removed from the first 20 c.c. that passed. As more solution flowed through, the amount of nitrogen in the percolate increased, until, when the thirteenth addition had been made, the tenth 20 c.c. of percolate came away practically unchanged. Percolation with ammonium sulphate solution was stopped at this point.

20 c.c. of the ammonium sulphate solution contained -0218 grms. of nitrogen and by subtracting the amount of nitrogen in every 20 c.c. of the percolate from this figure, the total amount retained after each addition of solution, was ascertained.

Sulphate was determined in the first five portions of the percolate and it was found none had been retained.

## REMOVAL OF THE AMMONIA BY WATER.

An attempt was now made to remove the ammonia by percolating distilled water 20 c.c. at a time, through the column.

Thirteen additions of ammonium sulphate solution had been made, but as it required slightly more than 40 c.c. of solution to saturate the granite, it was not until the third lot of distilled water had been added, that thirteen portions of percolate of 20 c.c. each were obtained.

The washing out of absorbed ammonia therefore properly began with the fourteenth portion, and there was present in the granite dust at this point, the total nitrogen added less the sum of the nitrogen recovered in the first thirteen portions of percolate ( $0.0218 \times 13 - 0.2321 = 0.0513$  gms. N). Percolation with water was continued until the percolates were practically free from nitrogen. The results are shown in Table VII.

As will be seen from the table, there was a gradual but comparatively slow removal of the absorbed ammonia—the rate of washing out falling off, until, when about 20 % of the total amount absorbed remained, the amount removed by 20 c.c. distilled water was practically negligible.

This bears out the conclusion arrived at by Voelcker for soils that the rate of washing out is slow compared with the rate of absorption. It would also appear that even where the absorption in soils is due to unweathered mineral matter there is little risk of appreciable quantities of absorbed ammonia being washed out.

The granite was removed from the percolator and the nitrogen retained determined by distillation with magnesia as before. This gave 0.0048 gms. nitrogen which left only  $0.0072 - 0.0048 = 0.0024$  gms. nitrogen unaccounted for. The conditions of the experiment were quite unfavourable to nitrification, and the balance was probably fixed in a less easily decomposable form.

It is difficult to determine in what form the ammonia is retained. Way(6) from his experiments on artificial silicates concluded that an almost insoluble double ammonium silicate was formed. Voelcker(7) and others have shown that when ammonium sulphate is added to the soil as manure, an insoluble nitrogenous compound is formed which remains in the soil while the calcium sulphate washes out in the drainage water.

Russell(8) found that the compound formed is not completely decomposed on distillation with magnesia and concludes that it does not seem to be an ordinary ammonium compound.

Since the sulphate is not retained by the soil or granite, but merely

the base, some other base must come through or free sulphuric acid be produced.

Table VII.

*Removal of Ammonia from Powdered Granite by Distilled Water.*

Number of percolate	Grms. nitrogen in 20 c.c. percolate	Grms. nitrogen retained by granite
14	·0048	·0465
15	·0042	·0423
16	·0028	·0395
17	·0022	·0373
18	·0022	·0351
19	·0018	·0333
20	·0017	·0316
21	·0017	·0299
22	·0014	·0285
23	·0014	·0271
24	·0014	·0257
25	·0013	·0243
26	·0013	·0229
27	·0013	·0216
28	·0012	·0204
29	·0012	·0192
30	·0010	·0182
31	·0010	·0172
32	·0010	·0162
33	·0010	·0152
34	·0009	·0143
35	·0007	·0136
36	·0007	·0129
37	·0007	·0122
38	·0006	·0116
39	·0006	·0110
40	·0006	·0104
41	·0005	·0099
42	·0005	·0095
43	·0004	·0091
44	·0004	·0087
45	·0003	·0084
46	·0003	·0081
47	·0003	·0078
48	·0002	·0076
49	·0002	·0074
50	·0002	·0072

The percolates with powdered granite showed no acidity to litmus, so that if free acid was produced it must have combined with other bases present in the granite. Analysis of a solution obtained by shaking

up a quantity of granite dust with ammonium sulphate solutions and filtering off the granite, showed that the base which chiefly replaced the ammonium was calcium. There was also an increase in potassium, sodium, magnesium and silica compared with a solution from the same quantity of granite dust and distilled water.

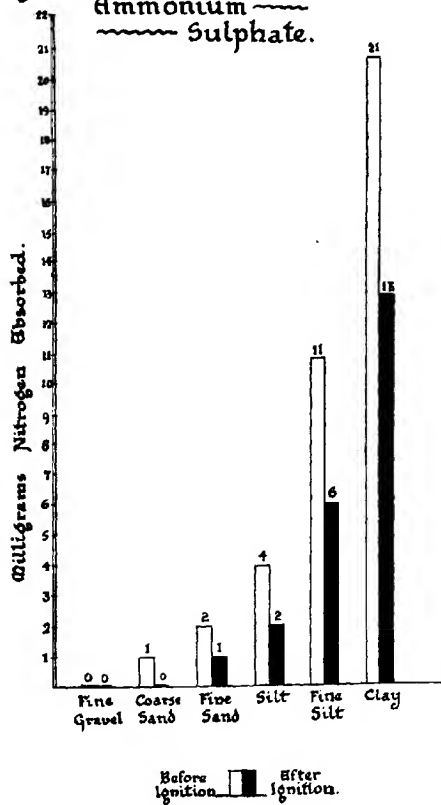
These results throw little light on the means of retention. But whatever be the mode, there is certainly a considerable power of absorption by powdered granite, and the ammonia so retained is not readily washed out. From the results of the percolation experiment it seems likely that the absorption by unweathered material at any rate is largely an adsorption effect—addition of solution causing a decrease in surface tension and a concentration of ammonia in the surface layer; addition of water increasing the surface tension and diminishing the concentration in the surface layer, i.e. negative adsorption.

#### CONCLUSIONS.

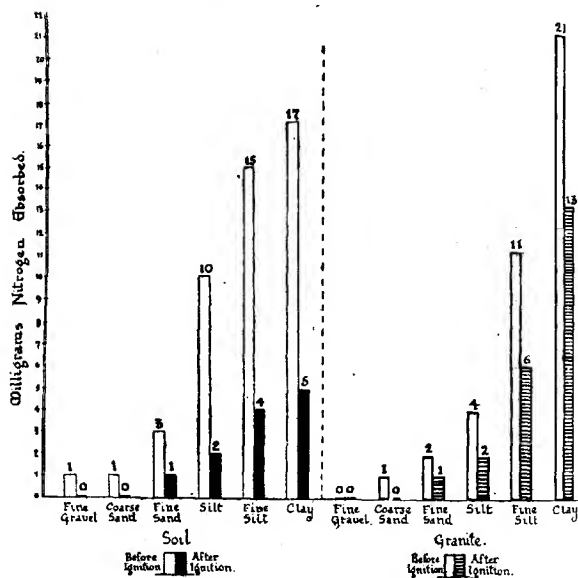
1. Powdered granite in a finely divided condition has a very considerable absorptive power.
2. Compared with fractions from Craibstone soil, granite fractions have a similar power of absorbing ammonia and it would appear that absorption is not by any means due to weathered materials, alone, but that unweathered materials have quite as great an absorptive effect.
3. The evidence indicates that the absorption does not increase proportionately to the increase of the surface with fractions of increasing fineness, but at a lower rate than the increase of surface.
4. After ignition there is a reduction in the absorptive power and this reduction is more marked in the case of the soil fractions.
5. The absorbed ammonia is only gradually washed out by water, but the whole of it is not removed in this way—a point being reached when practically no more ammonia is removed.
6. Absorption by powdered granite and probably also by the unweathered or little weathered materials in soils, seems to be largely an adsorption effect.

Publication of Parts II and III of this paper was delayed by the war. Since they were drafted a valuable résumé of the subject by Prescott has appeared in Vol. VIII of this *Journal*.

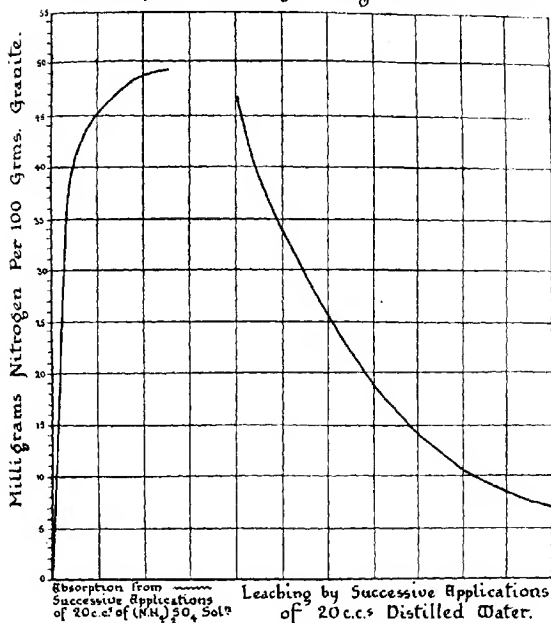
Absorption by 10 gram portions of  
the various fractions of powdered  
granite from a solution of ~~~~  
Ammonium ~~~~  
~~~~ Sulphate.



Absorption by 10 grams of the Various Fractions of  
Soil & Granite from 50 ccs of a solution containing  
5 Grams  $(\text{NH}_4)_2\text{SO}_4$  per Litre.



Absorption of Ammonia by Powdered Granite ~~~~  
& Subsequent Washing Out by Distilled Water.



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- (1) *Journ. of the Roy. Agr. Soc.* 1852, 13, 123-143.
- (2) *The Interaction between Minerals and Water Solutions*, 1907, *Bul.* 312. U.S. Geol. Survey.
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- (4) *Loc. cit.*
- (5) *Journ. Roy. Agr. Soc.* 1860, 21, 105-134.
- (6) *Loc. cit.*
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## COMPOSITION AND PROPERTIES OF OAT GRAIN AND STRAW.

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## 360 *Composition and Properties of Oat Grain and Straw*

### INTRODUCTION.

Investigations in connection with the oat crop have been carried on at the Experiment Station of the West of Scotland College of Agriculture, at Kilmarnock, since its inauguration in 1890. For several years preceding 1911 over a hundred seedsmen's varieties of oats were grown there annually. Variety tests were also carried out on a large scale on farms situated in the counties in the administrative area of the College. Their object was to test the yielding power of different varieties of oats and their suitability for cultivation under the varying conditions of farming in the south and south-western counties of Scotland. The results obtained have been issued from time to time in the form of College *Bulletins*<sup>1</sup>.

The material which these experiments provided seemed to offer an opportunity for a systematic study of the influence of variety, soil, climate, manures, etc. on the composition, character and yields of oat, grain and straw. With this object in view a commencement was made in the summer of 1909 to collect samples for analysis, and to accumulate other necessary data. The work has been continued at intervals up to the present time, and the results obtained are dealt with in the present paper.

### EXAMINATION OF THE GRAIN.

A three pound sample was taken to represent the bulk and, except in the case of imported oats, wild and native oats, "dressed" grain was used. Before analysis the grain was exposed on aluminium trays in the Laboratory for at least 24 hours.

#### A. MECHANICAL METHODS.

##### *Separation of the grain into kernel and husk.*

A sample of grain as a rule contained small but varying amounts of chaff, pieces of straw, weed seeds, and free kernels already husked (shelled grain). These were removed and their proportion in the sample determined before weighing out the whole grain for the separation of the husk.

The separation of the husk was a long and tedious process, the only trustworthy method being the dissection by hand of each individual grain. In the husking the little tuft of hairs situated at the apex of the kernel was mostly broken off and lost, but as the hairs formed only a small proportion of the weight of the kernel, the loss was insignificant.

<sup>1</sup> Wright, R. Patrick, "Experiments with Oats," *Bulletins* 12, 17, 18, 41. West of Scotland College of Agriculture, Glasgow.

These hairs form part of the oat dust. An example of the figures obtained for each sample is given below:

|                                |     |     |             |          |          |
|--------------------------------|-----|-----|-------------|----------|----------|
| Kernel, free                   | ... | ... | 1.20 grms.  | 4.84 %   |          |
| Weed seeds, chaff (Glume) etc. | ... | ... | 0.27 "      | 1.09 %   |          |
| Kernel                         | ... | ... | 17.51 "     | 70.53 %  | 74.96 %  |
| Husk (pale)                    | ... | ... | 5.85 "      | 23.54 %  | 25.04 %  |
|                                |     |     | 24.83 grms. | 100.00 % | 100.00 % |

• *Humidity of the atmosphere and its effect upon the weight of the grain.*

In some cases the combined weight of the husk and kernel was less, and in others more, than the original weight of the grain. During the husking the hygrometric condition of the atmosphere in the Laboratory was rarely the same at the time of the initial weighing, as it was at the time of the final weighing, and it was thought that this might partly account for the differences. The following figures are examples of each case.

A ten gram sample after husking weighed

|     |        | Next day           |                             |                             |
|-----|--------|--------------------|-----------------------------|-----------------------------|
|     |        | Afternoon<br>grms. | Forenoon<br>grms.           | Afternoon<br>grms.          |
| (1) | Kernel | ...                | 7.450                       | 7.470                       |
|     | Husk   | ...                | 2.500                       | 2.504                       |
|     |        |                    | 9.950                       | 9.988                       |
|     |        |                    |                             | 9.968                       |
|     |        | Afternoon<br>grms. | 2nd day<br>10 a.m.<br>grms. | 3rd day<br>11 a.m.<br>grms. |
| (2) | Kernel | ...                | 7.735                       | 7.726                       |
|     | Husk   | ...                | 2.264                       | 2.272                       |
|     |        |                    | 9.999                       | 9.998                       |
|     |        |                    |                             | 10.013                      |
|     |        |                    |                             | 10.034                      |

Variation in the weight was greatest after a night's frost. An attempt to do the initial and the final weighings under as near as possible the same atmospheric condition was not found to be practicable, and it would have added considerably to the time of the operation to have always worked on the "dry sample." It was therefore decided to obtain some idea of the effect of varying conditions of the atmosphere on the weight of the grain.

For this purpose 100 gram lots of each of the varieties - Potato, Sandy, Beseler's Prolific and Wide Awake - were weighed on aluminium trays and left exposed in the Laboratory for ten days, the weight of the grain being taken at regular intervals each day. The alteration in

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the weights recorded was practically the same for each variety. The results for the ten days have been averaged and they are given in the following table:

| Time    | Averages of weighings | Average temp. of atmosphere C. |
|---------|-----------------------|--------------------------------|
| 9 a.m.  | 100.81                | 8°                             |
| 10 „    | 100.86                | 8°                             |
| 11 „    | 100.93                | 10°                            |
| 12 noon | 101.02                | 13°                            |
| 1 p.m.  | 101.07                | 14°                            |
| 2 „     | 101.08                | 14°                            |
| 3 „     | 101.07                | 14°                            |
| 4 „     | 101.07                | 13°                            |
| 5 „     | 101.06                | 13°                            |

Between the hours of 9 a.m. and 2 p.m. each day there was a small increase, afterwards as the figures show, there was a slight falling off in the weight, and a gradual cooling of the air. The husk was more sensitive to the hygrometric condition than the kernel. Wilson<sup>1</sup> finds that the percentage of moisture in the husk and kernel of the ripe grain is practically always alike. This he attributes to the free and rapid interchange of moisture between the husk and kernel. The marked contrast between the early morning and noon-day temperature of the Laboratory was due to the absence of proper heating and to the fact that the season was mid-winter.

#### *Weekly variation in weight.*

In the course of ten days 100 grams of grain increased in weight to 101.68 grams. Weekly weighings of 100 gram lots of newly threshed grain of Potato and Wide Awake varieties respectively were then carried out over a long period. The weighings commenced on the 29th November and were continued weekly until the 18th September in the following year. The weekly rainfall and the temperature of the atmosphere were recorded. The results are expressed in the form of a curve (Fig. 1, p. 363).

During the winter months, the weight increased, the maximum increase amounted to about 1.5 % of the initial weight. With the advent of warmer and a relatively drier condition of the atmosphere the weight slowly diminished, the maximum decrease being about 3 % of the initial weight which was reached in the middle of June, whilst from this date until the end of the experiment, it increased again.

There is a certain amount of correlation between the rainfall, temperature, and weight variation curves. The lower weight generally

<sup>1</sup> Wilson, A. Stephen, *A bushel of Corn*, 1893, p. 290.

coincides with the low rainfall, and high temperature, and the reverse. The humidity of the atmosphere was calculated from the readings taken at Kilmarnock of the wet and dry bulb thermometer, using Regnault's

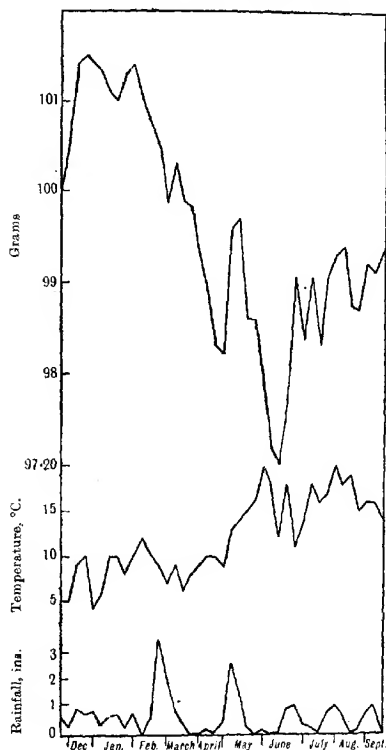


Fig. 1.

equations and Blanford's Psychrometer Table<sup>1</sup>. The result showed that the humidity of the atmosphere varied according to the rainfall and the

<sup>1</sup> Simpson, G. C. and Walker, Gilbert T., *Tables for the reduction of Meteorological Observations* issued by the Government of India, 1910.



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temperature, a low rainfall and a high temperature gave the relatively drier atmosphere.

#### *Variation in weight of a bushel of grain during storage.*

The alteration in the weight of a bushel of grain when stored in a granary over a period of several years was also determined. Two bushels of the grain of Wide Awake oat were measured into two sacks and accurately weighed, the weight of the sacks being 9 oz. respectively. Each sack was then weighed separately at three month intervals, the first weighing was in October 1912 and they were continued every three months until July 1915. The figures are given along with those for the rainfall in Fig. 2.

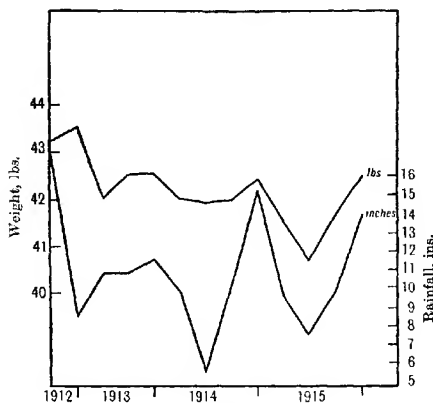


Fig. 2.

The weight was greatest at the first weighing which was made at the time of threshing. It continued to decrease for the first nine months, after that it varied according to the humidity of the air.

The actual loss in weight of the grain whether threshed or unthreshed for the first nine months depends primarily upon the water content at the time of stacking. In the present series of experiments, the water content of the grain at the time of cutting the crop was 42 % and of the straw 65 %. At the time of stacking after the sheaves had been standing in the stooks for about 21 days it fell to 18 and

22 % respectively. These figures are the averages of four varieties harvested in 1918. Similar determinations made in 1913 gave practically the same result.

The amount of desiccation which goes on while the crop is in the stook will of course depend principally upon the weather conditions. In a warm and comparatively dry climate such as commonly prevails in the south of England the crop is stacked in a drier condition compared with that in the west of Scotland. The average water content of the grain of the same varieties grown in the same year, several months after threshing, was found to be 12.2 % in the former and 14.4 % in the latter case (see p. 399 and imported oats). The highest in grain threshed in the month of October was 17.82 %, and the lowest found in the course of these experiments was 8.86 %.

The water content affects the yield per acre and the nutritive value of the grain, a factor which must be taken into account when considering these two points. Wilson<sup>1</sup> finds, other things being equal, that the bushel weight of grain containing a low percentage of water may be the same as that containing a high percentage of water. From this it follows that bushel weight must not be taken as an invariable index to meal power, a practice which is sometimes followed<sup>2</sup>. Although according to the following figures obtained from the same varieties of oat grown in different localities, there is a direct connection between bushel weight and meal powers:

| Natural weight<br>per bushel<br>lbs. |   | Yield of oatmeal<br>lbs. |
|--------------------------------------|---|--------------------------|
| 43.44                                | " | 210                      |
| 42                                   | " | 206                      |
| 41                                   | " | 203                      |
| 40                                   | " | 197                      |
| 39                                   | " | 193                      |
| 38                                   | " | 186                      |

For the influence of size of grain and thickness of husk on the weight per bushel see Tables, pp. 394 and 392.

In view of the foregoing determinations it was decided to calculate the results of the chemical analyses of the kernel given in this paper to the "dry state" or to a uniform moisture content and to record the percentage of moisture "as determined" in the sample. The results of the mechanical analyses are expressed in the "air dry" state.

<sup>1</sup> Wilson, A. Stephen, *A bushel of Corn*, 1883, p. 154.

<sup>2</sup> Clark, J. F. and Adams, H. B., "Phenological observations in the British Isles from Dec. 1914 to Nov. 1915," *Royal Meteorological Soc.*, 1916, **42**, No. 180.

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Twenty-five grams in duplicate were used for the husking. Latterly 12.5 grams in duplicate were found to give concordant results.

*Weight of 1000 grains* and kernels respectively was determined in every sample examined.

#### B. CHEMICAL METHODS.

The kernel, and in many cases the grain from the same sample, were respectively ground to a meal and duplicate quantities were weighed out for the determination of water, oil, fibre, ash and nitrogen.

*Water.* Preliminary determinations of the water content were not consistent. For example 5 grams of meal were weighed out daily from a quantity contained in a stoppered bottle, into a platinum capsule, and dried in the ordinary way in a steam oven for five hours. The results of the separate estimations were 12.43, 12.63, 12.38, 12.45, 12.42, 12.20, 12.28 % of water respectively. The temperature inside the steam oven was registered and it was found to vary from 92° to 98° C. The higher temperature invariably gave the higher water content.

The effect of drying for a prolonged period and weighing at definite intervals was tried with the following results:

|                      |         |       |
|----------------------|---------|-------|
| After 5 hours drying | 9.32 %  | water |
| „ 9 „ „              | 10.01 % | „     |
| „ 11 „ „             | 9.88 %  | „     |
| „ 13 „ „             | 9.88 %  | „     |
| „ 15 „ „             | 9.75 %  | „     |
| „ 17 „ „             | 9.61 %  | „     |

Another sample was dried in (1) carbon dioxide gas after bubbling the gas through strong sulphuric acid, and (2) in dry air respectively, and a water content of 12.92 % was obtained in both cases. The operation was carried out in a special drying apparatus. The control determination made in the ordinary steam oven gave 12.42 %. The temperature in the former registered 100° C. and in the latter 95° C.

In view of these results the determination of water was carried out in 5 grams of meal, dried for nine hours in the steam oven with the water actively boiling. See also a recent paper by Birchard<sup>1</sup> on moisture in wheat flour.

*Crude fat (the ether extract).* Micro-chemical tests using cyanin (Grubler's) for staining, shows the oil to be located in the aleurone layer, and in the embryo. The latter formed from 2.5 to 4 % by weight of the kernel and contained between 26 and 27 % of ether extract, so that from

<sup>1</sup> Birchard, F. T., *Journ. Soc. Chem. Ind.*, 1918, **37**, No 16, pp. 263-265.

11.25 to 12.25 % of the total extract of the kernel is in the embryo. The extract from the ground kernel was invariably cloudy, due to the presence of finely divided suspended matter most of which passed through the filter paper thimble at the commencement of the extraction. After evaporating off the ether a brown opalescent oil was left. While drying the oil, it was noticed, that the addition of a few drops of water caused the suspended matter to separate out as a yellow solid, leaving the oil clear. By re-dissolving the oil in ether and either filtering or decanting off the ethereal solution, the solid could be separated. The amount of the solid varied in different samples from about 0.25 to 6 % of the total extract. In a few cases the oil was quite clear. The solid contained phosphorus.

Stellwaag<sup>1</sup> obtained a turbidity in ether extractions from oats, which he clarified by filtration through porous earthenware pots. He also identified cholesterol and obtained a wax-like body. Osborne and other investigators have shown the presence of a lecithide in oats. According to Soxhlet the percentage of lecithide is 1.31 and of cholesterol 2.28. Schulze<sup>2</sup>, Winterstein and Hiestand<sup>3</sup> state that the lecithide is in combination with a carbohydrate and they have identified galactose and other sugars.

As the ether extract contained solid matter, other solvents were tried, in a Soxhlet extraction apparatus, with the following results:

Table I. *Dry meal extracted with different solvents.*

|                     |                   | Percentages                  |                  |         |            |                 |                      |         |
|---------------------|-------------------|------------------------------|------------------|---------|------------|-----------------|----------------------|---------|
| Hours of extraction |                   | Dry ether                    | Absolute alcohol | Acetone | Chloroform | Petroleum ether | Carbon tetrachloride | Benzene |
| First               | 5 hour extraction | 8.82                         | 10.89            | 9.22    | 9.65       | 8.52            | 9.17                 | 9.28    |
| Second              | " "               | 0.19                         | 0.62             | 0.88    | 0.24       | 0.27            | 0.25                 | 0.89    |
| Third               | " "               | 0.19                         | 0.26             | 0.27    | 0.21       | 0.14            | 0.17                 | 0.24    |
| Total               | ... ..            | 9.20                         | 11.77            | 10.37   | 10.10      | 8.93            | 9.59                 | 10.41   |
|                     |                   | Percentages of total extract |                  |         |            |                 |                      |         |
| First               | 5 hour extraction | 95.68                        | 92.52            | 88.90   | 95.54      | 95.41           | 95.62                | 89.24   |
| Second              | " "               | 2.06                         | 5.27             | 8.48    | 2.38       | 3.02            | 2.60                 | 8.55    |
| Third               | " "               | 2.06                         | 2.21             | 2.61    | 2.08       | 1.57            | 1.78                 | 2.21    |

The different extracts varied in amount considerably. Taking the ether extract as 100 the proportion given by the other solvents are—

<sup>1</sup> Stellwaag, A., *Landw. Versuchs-Stat.*, 1890, **37**, p. 135.

<sup>2</sup> Schulze, E., "Ueber den Phosphorgehalt einiger aus Pflanzensamen dargestellter Lecithin präparate," *Zeitsch. Physiol. Chem.*, 1907, **52**, pp. 54-61

<sup>3</sup> Winterstein, E. and Heistand, O., "Beiträge zur Kenntnis der Pflanzleichen, Phosphatide II," *Zeitsch. Physiol. Chem.*, 1907, **54**, pp. 288-330.

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petroleum ether 97.07, carbon tetrachloride 104.24, chloroform 109.8, benzene 113.11, acetone 112.72, ethyl alcohol 127.93. The rate at which the extractable substances were removed by the different solvents varied. Ether, chloroform and petroleum ether extracted over 95 % of the total extract in the first five hours. The oil from the alcohol and chloroform extract was distinctly turbid. In none of the others was it clear. Invariably the second and third five hour extractions were partly solid. In the case of chloroform it was crystalline.

The ether extractions, were repeated six times, making a total of 30 hours and the last extraction still yielded a slight residue.

Prolonged digestion by the solvent, removed substances from the oat other than true fats, such as those mentioned above, with possibly some products arising from a certain amount of hydrolysis of the fatty substances produced while the extraction is in progress. The alcohol extract may include in addition some protein matter<sup>1</sup>, sugar<sup>2</sup> and a compound of the nature of an alkaloid<sup>3</sup>, the presence of the latter in oats still requires confirmation<sup>4</sup>.

Of the different solvents, petroleum ether, and ordinary ether, gave the clearer extracts. It was decided to use the latter for the extraction of the oil, it being the solvent in more general use for the purpose.

A comparison of the extract, from dry meal, and air dry meal, using dry ether, and ordinary ether, was made, with the following average results, calculated to the dry meal:

|              |     | Dry ether | Ordinary ether |
|--------------|-----|-----------|----------------|
| Dry meal     | ... | 9.25 %    | 9.43 %         |
| Air dry meal | ... | 9.40 %    | 9.72 %         |

The effect on the ether extract of drying the meal in dry air, compared with dry carbon dioxide, gave an average figure of 7.6 % for the former, and 7.47 % for the latter including in the first case 0.96 % of free fatty acid calculated as oleic, and 0.79 % in the second case. The amount of free fatty acid in the extractions previously recorded, was not determined.

*Free fatty acids.* The amount of free fatty acid in the oil was afterwards determined in a number of samples and it was found to vary considerably. In the freshly ground meal the proportion of free

<sup>1</sup> "Proteins and albuminoids of the Oat kernel," by Thomas B. Osborne, *Am. Chem. Journ.*, 1891, **13**, p. 327; 1892, **14**, p. 212.

<sup>2</sup> See Table XXVIII, p. 413.

<sup>3</sup> "Irritant properties of Oats," by Sanson Bield, *Cent.*, 1884, pp. 20-21.

<sup>4</sup> "Existence of Avenin," by E. Wrampelmeyer, *Landw. Versuchs-Stat.*, **36**, pp. 299-301.

acid is small, but hydrolysis of the oil rapidly takes place as will be seen from the following figures:

|       |      |     |                    |                  |
|-------|------|-----|--------------------|------------------|
| June  | 6th  | ... | 11.3 $\frac{g}{g}$ | free acid in oil |
| "     | 10th | ... | 26.2 $\frac{g}{g}$ | " "              |
| "     | 17th | ... | 46.7 $\frac{g}{g}$ | " "              |
| "     | 24th | ... | 51.5 $\frac{g}{g}$ | " "              |
| July  | 1st  | ... | 55.5 $\frac{g}{g}$ | " "              |
| "     | 8th  | ... | 55.6 $\frac{g}{g}$ | " "              |
| Aug.  | 12th | ... | 59.9 $\frac{g}{g}$ | " "              |
| Sept. | 2nd  | ... | 63.2 $\frac{g}{g}$ | " "              |
| "     | 23rd | ... | 63.5 $\frac{g}{g}$ | " "              |

According to Stellwaag one-third of the ether extract of oats consists of free fatty acids while König<sup>1</sup> states that it is mainly composed of free acids.

From the above figures the amount of the free acid in the oil evidently varies according to the time which elapses between the grinding of the grain and the extraction. In the freshly ground kernel the extract is nearly neutral. The effect of heating the grain for several hours at about 100° C. such as is done in the manufacture of oatmeal, is to slow down the rate of hydrolysis, but the amount of acid ultimately liberated is the same.

The oat oil was saponified and the proportion of liquid free acids obtained amounted to 76.5 % of the total fatty acids, the remainder being solid. The separation of the liquid from the solid acids, was obtained by first making the lead salts, and then separating by their difference in solubility in ether, the former being soluble and the latter insoluble. Small amounts of unsaponifiable matter were found in all the extracts examined.

For the determination of the ether extract 5 grams of meal after drying in a steam oven, were extracted with ether dried over quick lime, for fifteen hours in a Soxhlet extraction apparatus.

*Crude fibre.* The usual method for the determination of crude fibre was adopted, and which consisted in boiling 5 grams of meal in 200 c.c. of 1.25 % sulphuric acid and 1.25 % caustic soda respectively for 30 minutes each, water being added from time to time to correct for loss while boiling. Afterwards the fibre was digested with alcohol and ether, before drying and weighing. These two latter solvents, removed an oil, which was accumulated for further examination, and it amounted to about 30 % of the total weight of crude fibre. The actual percentage of crude fibre obtained in the kernels was invariably lower than those

<sup>1</sup> König, J., *Landw. Versuchs-Stat.*, 1884, p. 161.

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given by Hendrick<sup>1</sup>. By using meal which had been previously extracted of oily substances with ether, the weight of fibre obtained was slightly lower than when unextracted meal was used.

*Ash.* The dried meal from the water determination, was first charred in a platinum dish over a low bunsen flame, and ultimately burnt at the full heat of the flame. The ash as a rule fused, and often contained traces of unburnt carbon. For the determination of phosphoric acid, potash, and other constituents, the usual methods were employed. *Total nitrogen* was determined in 1 gram of meal by the Kjeldahl method. See Table XIV for water soluble nitrogen. *The soluble carbohydrates* were undetermined, but their amount was calculated by difference.

#### ABSORPTION AND DISTRIBUTION OF NITROGEN AND MINERAL CONSTITUENTS IN THE GROWING OAT.

It is a well established fact that the amount of nitrogen and mineral compounds absorbed from the soil by cereal crops is, in a measure, an index to the supplies available. Brechley and Hall<sup>2</sup> find that their absorption continues within a few days of maturation. Pierre<sup>3</sup> on the other hand holds that the plant ceases to draw nutriment from the soil at the flowering stage or a little later. Stutzer<sup>4</sup> shows that between 50 and 60 % of the total nitrogen contained in the ripe plant, was absorbed in the first four weeks of growth.

Their distribution throughout the plant is also subject to interference. In one of the older publications<sup>5</sup> it is remarked that "when the climate is dry and warm the panicles of the oat are so dried and restricted that they cease to convey sufficient nutriment to the ears which thus never become plump, but thin husked, long awned and unproductive of meal."

They may be also in part returned to the soil again either through the roots or by their excretion on the leaves and stems from which they are removed by the action of rain and wind. According to Le Clerc

<sup>1</sup> Greig, R. B. and Hendrick, James, "Report on the composition and merits of Varieties of Oats," *Bull.* No. 2, 1905; No. 6, 1906, Aberdeen and North of Scotland College of Agriculture.

<sup>2</sup> Brechley, W. E. and Hall, A. D., "The development of a grain of wheat," *Journ. Ag. Sc.*, 3, Pt II, pp. 196-217.

<sup>3</sup> Pierre, J., *Min. Soc. Linnéenne de Normandie*, 15, 1859, pp. 1-220.

<sup>4</sup> Seidler, Albert and Stutzer, "Assimilation and elimination of nutrients by oats at different periods of vegetation," *Journ. Landw. Versuchs-Stat.*, 1903, 56, pp. 273-278.

<sup>5</sup> London's *Encyclopedia of Agriculture*, 1883, p. 286.

and Breazeale<sup>1</sup>, of the totals absorbed by the growing oat, 2 % of the nitrogen, 33 % of the phosphoric acid and 36 % of the potash, were subsequently lost again before the plant was ripe.

As the question of variation in the composition and other characters of the plant are influenced by such factors as the foregoing, it was decided to obtain some preliminary data on the points raised under the conditions which prevail at Kilmarnock<sup>2</sup>.

#### PLAN OF THE EXPERIMENT.

A section of a field of Wide Awake oats where the crop appeared to be uniform was decided upon. Samples for analysis were taken every fortnight, and continued until the crop was harvested. The first cutting was made on 7th June, 1912 after a growth of 63 days. As a sample 200 complete straws in duplicate were taken at each cutting. The straw was cut immediately above the first node showing through the soil. The crop was sown on the 30th March and cut on the 16th August, making a growing period of 139 days. The ear which was first separated from the straw was dissected into chaff, kernel and husk, each, including the straw, being weighed and dried for analysis. The nitrogen, ash, and other constituents, were determined in the dry sample.

The rate of absorption of, and the distribution, between the straw and the grain of the various plant constituents during growth, are represented in Fig. 3, p. 372.

*Nitrogen.* The absorption of nitrogen appears to be almost complete at the stage when the kernel begins to develop as from this point onwards the gain in nitrogen by the plant was only very slight and was well within the limits of the experimental error. From the appearance of the plant, growth seemed to continue up to the time when the crop was cut. The stem was still greenish at the final cutting. The storage of nitrogen in the kernel appears therefore to be carried on entirely from the supplies contained in the straw, husk, and chaff. The total weight of nitrogen in the straw, was less at harvest time in the month of August, than it was early in the month of June.

*Potassium.* The curve for the potash absorption and distribution, except at one of the cuttings, resembles that for nitrogen. The withdrawal of potash into the seed is on a small scale compared with that of nitrogen and the amount absorbed by the plant during the last six weeks

<sup>1</sup> Le Clere, J. A. and Breazeale, J. F., "Plant foods removed from growing plants by rain and dew," *Year book Dept. of Ag. U.S.A.*, 1908, pp. 389-402.

<sup>2</sup> See Tables XXIX and XXX for Meteorological and soil conditions at Kilmarnock.



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of growth is almost equal to that passing into the seed. There is therefore little exhaustion of the total potash supply contained in the straw.

*Ash and phosphoric acid.* The assimilation of "total ash" and of phosphoric acid, continued until the plant was mature, though it was

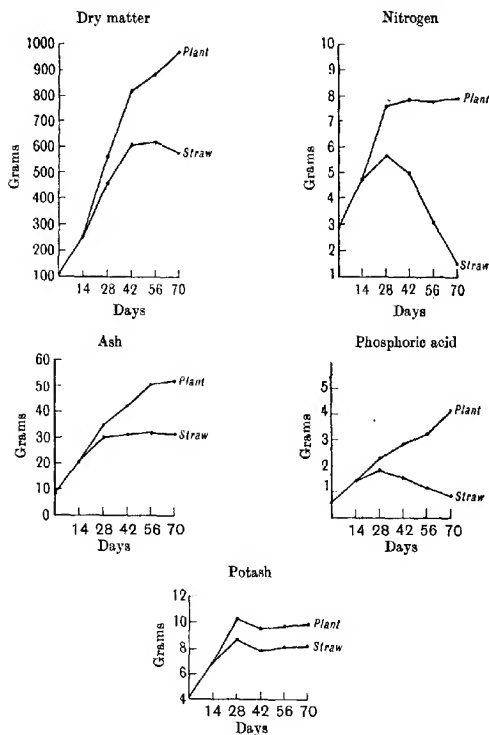


Fig. 3.

carried on to a diminishing extent towards the end of the growing period. The amount of the latter absorbed in the later stages of growth, falls below that which passes into the seed, in consequence, the phosphorous content of the straw diminishes accordingly.

In plants of about two months' growth, that is several weeks before the stem had attained its maximum height, it was found that the phosphoric acid and the potash together, formed about 50% of the total weight of ash absorbed. As growth proceeds the ratio rapidly falls, the figures for the fortnightly cuttings being 49.4, 42.1, 32.8, 29.0, 25.3 and 27.0 % respectively. The total weight of magnesia and lime absorbed is relatively small. The predominating constituents of the mineral matter are compounds of silicon the proportion of which continue to increase until the plant approaches maturity.

The relative proportion of nitrogen, phosphorus, potassium and ash in the separate plant organs at the different stages of growth are given in Table II below.

Table II.

*This table shows the relative proportion of nitrogen, ash, phosphoric acid, and potash in plant organs at different stages of growth.*

|                             |     | July  |      | August |       |
|-----------------------------|-----|-------|------|--------|-------|
|                             |     | 5th   | 19th | 3rd    | 16th  |
| Percentages of the total    |     |       |      |        |       |
| Nitrogen.                   |     |       |      |        |       |
| Straw ...                   | ... | 73.7  | 63.2 | 41.1   | 18.5  |
| Kernel...                   | ... | 26.3* | 15.4 | 42.9   | 70.0  |
| Chaff ...                   | ... | —     | 6.2  | 5.1    | 4.3   |
| Husk ...                    | ... | —     | 15.2 | 10.9   | 7.2   |
| Ash.                        |     |       |      |        |       |
| Straw ...                   | ... | 53.0  | 75.6 | 67.0   | 62.1  |
| Kernel...                   | ... | 17.0* | 4.0  | 6.8    | 11.1  |
| Chaff ...                   | ... | —     | 9.4  | 10.0   | 10.9  |
| Husk ...                    | ... | —     | 11.0 | 16.2   | 15.9  |
| Phosphoric acid. $P_2O_5$ . |     |       |      |        |       |
| Straw ...                   | ... | 86.8  | 58.4 | 38.7   | 21.7  |
| Kernel...                   | ... | 13.2* | 23.2 | 56.5   | 76.2  |
| Chaff ...                   | ... | —     | 6.2  | 4.2    | 2.1   |
| Husk ...                    | ... | —     | 12.2 | 0.6    | trace |
| Potash. $K_2O$ .            |     |       |      |        |       |
| Straw ...                   | ... | 80.2  | 82.6 | 87.4   | 85.1  |
| Kernel...                   | ... | 19.8* | 5.8  | 7.1    | 10.2  |
| Chaff ...                   | ... | —     | 3.4  | 2.0    | 1.5   |
| Husk ...                    | ... | —     | 8.2  | 3.5    | 3.2   |

\* Grain.

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#### *Return of plant constituents to the soil.*

The rate of absorption of the different constituents and the amounts present in the whole plant were arrived at by determining the percentage of each in the straw and other organs at each of the cuttings and from the weights of each of these, the totals were calculated. This method would not of course show directly whether there had been a subsequent return of nitrogen and mineral compounds, through the root or lost from the plant by the action of rain and wind, to the soil.

It is well known that after the straw becomes ripe, the washing and leaching action of rain water will in course of time remove from the straw considerable amounts of its constituents. The author has found this to be the case particularly with dead bracken<sup>1</sup> and hay. Had the total weight of absorbed nitrogen and potash in the present experiment diminished at any of the successive cuttings it would have indicated subsequent losses. In any case if there had been a loss in the later stages of growth, it is probably small, and must have been confined to within the limits of the amounts absorbed in the period in question. For example with nitrogen and potash the ingress would be counter-balanced by the egress from the time when absorption of these compounds from the soil appeared to cease.

No figures were obtained showing the available nitrogen and potash supplies contained in the soil at the different stages of growth in the life of the crop, but the soil, judging from its analysis and from the appearance of the crop, was in an average state of fertility. The influence of the supplies of mineral and nitrogen compounds in the soil, upon the process and rate of their absorption by the plant are therefore not shown in these results.

#### *Silica and phosphate absorption.*

There did not appear to be any connection between the amounts of these two substances absorbed. The possibility of this was looked for in view of a relationship which was shown by Hall and Morrison<sup>2</sup> to exist between the supply of soluble silicates and the amount of soil phosphate absorbed. Kreuzhaga and Wolff<sup>3</sup> found in water culture experiments that the presence of silicates increased both the number and the

<sup>1</sup> Berry, R. A., "Utilisation and eradication of Bracken," *Bulletin*, West of Scotland College of Agriculture, Glasgow, 1917.

<sup>2</sup> Hall, A. D. and Morrison, *Proc. Royal Soc.* 1906, p. 445.

<sup>3</sup> Kreuzhaga and Wolff, *Landw. Versuchs-Stat.*, 1884, p. 161.

weight of the grain and helped the plants to mature. They go so far as to state that in the absence of silicates the grain is empty unless an excess of phosphorus is present.

The total dry matter of the plant increased during the whole growing period, although the maximum amount of dry matter contained in the straw is reached between two or three weeks before the plant is mature. The average height in inches of the straw at each of the fortnightly cuttings was 12.5, 23, 42, 42 and 43 inches respectively.

The following curves show the composition of the straw at each of the cuttings.

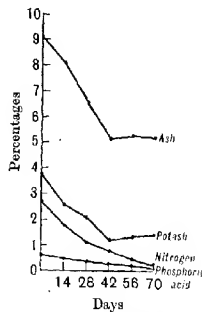


Fig. 4. Dry straw.

#### CHANGES IN THE COMPOSITION OF THE GRAIN AS IT DEVELOPS.

Data upon this point were considered necessary to fit in with the other figures on oats obtained under the conditions prevailing at Kilmarnock. Accordingly samples were taken every three or four days from a crop of growing oats (variety Mounted Police) as soon as the kernel was large enough to be readily separated from the rest of the grain. As before the samples were dissected into grain, straw, kernel, husk and chaff, each portion being weighed and dried for analysis. The proportions of these in the whole plant is given in Table III, p. 376.

*Kernel.* The actual weight of nitrogen and of ash, including phosphoric acid, and potash, in the kernel was determined at each of the cuttings, and the results are represented in Fig. 5. The percentages of the different constituents in the dry matter, are given in Table XXVIII in the Appendix.

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According to the above curves, which are self explanatory, the migration of the ash, nitrogen, phosphoric acid, and potash, from the straw and leaves, into the kernel, proceeds on similar lines to that shown by

Table III.

*This table shows in percentages the proportion of straw, kernel, husk and chaff in the dry plant at different stages of growth.*

| Variety: Mounted Police |      |      |      |      |        |      |      |      |  |
|-------------------------|------|------|------|------|--------|------|------|------|--|
| July                    |      |      |      |      | August |      |      |      |  |
|                         | 20th | 24th | 27th | 31st | 3rd    | 7th  | 10th | 14th |  |
| Straw ...               | 77.1 | 74.4 | 71.2 | 65.6 | 62.2   | 56.9 | 55.6 | 51.9 |  |
| Kernel ...              | 5.4  | 9.3  | 14.0 | 19.6 | 23.5   | 28.3 | 30.6 | 32.1 |  |
| Husk ...                | 13.2 | 12.9 | 10.7 | 11.7 | 10.6   | 11.2 | 10.3 | 11.7 |  |
| Chaff ...               | 4.3  | 3.4  | 4.1  | 3.1  | 3.7    | 3.6  | 3.5  | 4.3  |  |
| Kernel in grain %       | 19.0 | 55.4 | 61.7 | 66.9 | 69.3   | 72.2 | 73.2 | 74.1 |  |

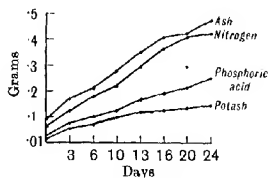


Fig. 5. Weights in 1000 dry kernels.

Table IV. *Percentage composition of dry matter of chaff and husk at different stages of growth.*

| Variety: Wide Awake          |      |        |       |       |      |      |        |  |  |
|------------------------------|------|--------|-------|-------|------|------|--------|--|--|
| Chaff                        |      |        |       |       | Husk |      |        |  |  |
| July                         |      | August |       |       | July |      | August |  |  |
| 5th                          | 19th | 3rd    | 10th  |       | 19th | 3rd  | 16th   |  |  |
| Dry matter ...               | 36.5 | 41.7   | 47.3  | 60.2  | 59.8 | 68.1 | 71.5   |  |  |
| Nitrogen ...                 | 1.94 | 1.33   | 1.16  | 0.68  | 0.99 | 0.75 | 0.46   |  |  |
| Ash ...                      | 6.21 | 9.41   | 15.05 | 18.00 | 3.73 | 4.43 | 6.05   |  |  |
| Phosphoric acid $P_2O_5$ ... | 0.43 | 0.41   | 0.40  | 0.31  | 0.28 | 0.25 | 0.059  |  |  |
| Potash $K_2O$ ...            | 1.33 | 0.76   | 0.49  | 0.47  | 0.62 | 0.37 | 0.34   |  |  |
| Lime $CaO$ ...               | 0.27 | 0.36   | 0.41  | 0.59  | 0.06 | 0.09 | 0.13   |  |  |

Hall and Brenchley to be the case with wheat. The ether extract of oats, is much greater than in wheat, or barley, and it forms a characteristic constituent of oat grain. The proportion of phosphoric acid in the ash, increased from 42 to 52 % while the potash decreased from 40 to 31 %.

*Straw.* The main points in connection with the composition of the straw during the growing period has already been indicated on pp. 371 and 372. See Table XXVIII, Appendix, for the composition of the straw.

*Chaff and Husk.* The composition of these organs at the different stages in their development is shown in Table IV, p. 376.

The table explains itself and no further comment is necessary.

*Ratios between the constituents of the grain.*

The ratios between different constituents of the grain, and between the same constituents in the grain and straw, have been worked out and are contained in Table V.

Table V.

| Kernel     | July |      |      |      | August |      |      |      |
|------------|------|------|------|------|--------|------|------|------|
|            | 20th | 24th | 27th | 31st | 3rd    | 7th  | 10th | 14th |
| Ash        |      |      |      |      |        |      |      |      |
| $P_2O_5$   | 2.37 | 2.3  | 2.12 | 2.13 | 2.13   | 2.08 | 1.97 | 1.90 |
| Nitrogen   |      |      |      |      |        |      |      |      |
| $P_2O_5$   | 1.79 | 1.79 | 1.77 | 1.74 | 1.73   | 1.89 | 1.95 | 1.73 |
| Oil        |      |      |      |      |        |      |      |      |
| $P_2O_5$   | 6.83 | 8.86 | 9.63 | 11.1 | 8.94   | 8.33 | 7.26 | 6.13 |
| Oil        |      |      |      |      |        |      |      |      |
| Nitrogen   | 3.9  | 4.9  | 5.3  | 6.3  | 5.1    | 4.4  | 3.6  | 3.5  |
| Ash        |      |      |      |      |        |      |      |      |
| Nitrogen   | 1.32 | 1.28 | 1.19 | 1.22 | 1.23   | 1.10 | 1.00 | 1.1  |
| Grain      |      |      |      |      |        |      |      |      |
| Straw N    | 5.2  | 4.7  | 5.1  | 5.2  | 6.0    | 7.0  | 7.2  | 9.9  |
| " $P_2O_5$ | 5.0  | 5.4  | 4.7  | 4.8  | 4.5    | 5.1  | 6.3  | 6.9  |
| " $K_2O$   | 1.4  | 1.4  | 1.1  | 1.1  | 0.87   | 0.87 | 0.78 | 0.7  |

INDIVIDUAL GRAINS IN THE SPIKELET.

The grains in the oat ear are borne in spikelets. Each spikelet consists of either a single grain (singles) or a pair of grains (doubles) or grains in triplets (trebles). A double contains a large grain (firsts) and a small grain (seconds or bosom pickle). A treble contains a large grain (firsts) and a very small grain (thirds) the seconds being intermediate sized grains. In addition to differences in size, the component grains in the spikelet vary in the thickness of the husk and in their chemical composition as shown in the average figures contained in Table VI, p. 378. The grains were separated by hand from the ears and spikelets.

A sample of oats may therefore be composed of several kinds of grain which differ from each other in size and in composition. The

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smaller grains, that is the seconds of the doubles, and the thirds from the trebles, will be partly winnowed out in the dressing of the grain, and will go to form the "light corn." The actual proportion of singles, doubles and trebles in the ear varies in different varieties as indicated in the table below. Moreover, the proportion in individual varieties is not fixed and will alter according to circumstances. Under favourable conditions of growth the maximum number of grains in the spikelet are developed, but when the processes of growth are curtailed, fewer spikelets, often with fewer grains, are produced, and the character of the sample will be influenced accordingly.

Table VI.

*Table VI shows the proportion by weight, and the percentage composition of the dry matter, of the kernels in the ear.*

|                          |                     |       |            | Doubles |        | Trebles |        |                |
|--------------------------|---------------------|-------|------------|---------|--------|---------|--------|----------------|
|                          |                     |       |            | Singles | Firsts | Seconds | Firsts | Seconds Thirds |
| Kernel.                  | Wt of 1000.         | grms. | ...        | 21.4    | 27.6   | 14.0    |        |                |
| Kernel.                  | Percentage in grain | ...   | ...        | 73.1    | 73.3   | 79.7    |        |                |
| Nitrogen in dry kernel   | ...                 | ...   | ...        | 2.46    | 2.43   | 2.32    |        |                |
| Oil                      | "                   | "     | ...        | 9.21    | 8.63   | 9.09    |        |                |
| Ash                      | "                   | "     | ...        | 2.11    | 2.22   | 2.10    |        |                |
| Proportion by wt in ear: | Potato              | ...   | ...        | 62.9    | 26.8   | 10.3    |        |                |
| "                        | "                   | "     | Sandy      | 80.1    | 13.4   | 5.6     |        |                |
| "                        | "                   | "     | Record     | 48.2    | 37.8   | 13.9    |        |                |
| "                        | "                   | "     | Wide Awake | 1.8     | 59.7   | 38.5    |        |                |
| Kernel.                  | Wt of 1000.         | grms. | ...        | 23.1    | 37.0   | 24.6    | 42.6   | 32.9 15.3      |
| Kernel.                  | Percentage in grain | ...   | ...        | 72.0    | 76.4   | 81.2    | 75.4   | 80.5 84.3      |
| Nitrogen in dry kernel   | ...                 | ...   | ...        | 2.24    | 2.36   | 2.23    | 2.55   | 2.51 3.41      |
| Oil                      | "                   | "     | ...        | 7.70    | 7.63   | 7.75    | 7.01   | 7.55 8.05      |
| Ash                      | "                   | "     | ...        | 2.07    | 2.31   | 1.94    | 2.28   | 2.0 2.04       |
| Proportion by wt in ear: | Kinness...          | ...   | ...        | 7.9     | 46.2   | 29.4    | 8.1    | 5.8 2.6        |

The statement sometimes made that the smaller grains in a fully developed ear, are richer in nitrogen than the larger grains in the same ear, is not supported by the above figures, in fact the tendency is in the opposite direction. Although the nitrogen content of the thirds from the trebles in the example given, is very high, in another case (Beseler's Prolific) it was the lowest of the three grains forming the trebles.

#### VARIETIES OF OATS.

The grain of over 120 seedsmen's varieties of oats, including the Wild, Tiree and Shetland Native oats, have been analysed, and with the exception of the last two, were all grown at Kilmarnock. Samples

of the grain of most of the varieties were analysed each year for three years, so that the figure given is in most cases the average of three analyses. For samples of the Shetland native oats, and for information respecting the cultivation and yielding power of these oats, the writer is indebted to W. Laidlaw Macdonald, Esq., of Sunburgh and to W. MacLennan, Esq. of Kirkwall, and for samples of the Tiree oat to Malcolm McLean, Esq. of Kirkapool, Tiree. As the native oats do not fit in with a grouping of the grain of the cultivated oats they are considered separately.

*Shetland Native oat (Avena strigosa)* includes a grey, and a black, variety. These oats are still grown, and used as bread corn, on the small holdings worked by cotters and fishermen on the poorer land in the Shetland Isles, where according to Evershed<sup>1</sup> the ancient system of cultivation is still to be seen in practice. The cultural conditions are such, that attempts to grow a modern variety, have been a failure. They rapidly deteriorate, whilst the native oat, can be grown to produce a moderate yield of grain and straw. On the better class of land in the Orkneys, Potato, Sandy and Myrtle Black oats can be grown successfully with suitable manuring.

The average yield per acre of grain of the Shetland oat, for the five years previous to 1916, is given as 20 bushels weighing 24.3 lbs. per bushel, and 20.3 cwt. of straw, compared with 31 bushels weighing 40 lbs. per bushel, and 48 cwt. of straw, for the Potato oat.

*Tiree Native oat.* Appears to be the same as the Shetland. It is practically the only variety which will thrive on the sandy and exposed parts of this Island. It is used mainly as fodder.

*Wild oat (Avena fatua).* The grain of this variety has been analysed, and the result is included along with those of the native oats in Table VII, p. 380.

*Chinese naked oat* was grown in this country before the year 1259<sup>2</sup>. It is the pilmorn of the old agriculture.

Although the proportion of kernel in the grain of the Native oats is low, the husk is very thin. By clipping off the awns, the proportion of kernel was increased from 68.7 to 73.8 %.

The terms, small corn, small grey, small black, black bearded, shiacks, rough oats, etc., which frequently occur in the agricultural

<sup>1</sup> Evershed, Henry, "The Agriculture of the Island of Shetland," *Trans. H. and Ag. Soc. of Scotland*, Fourth Series, 1874, 6, p. 200.

<sup>2</sup> Rogers, J. E. T., *List of rarer kinds of grain*, 1259-1400, 2, 1866, pp. 173 and 177. Gerarde, John, *The Herbal of General History of Plants*, 1537, p. 310.



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literature<sup>1</sup> of an early period seems to apply both to these oats and to others which have degenerated. References<sup>2</sup> as to the identity of the Shetland oat, with the common oat in cultivation in early times, are also made.

Table VII.

|                   |                     |       |     |     | Native oats |       |       |       | Chinese<br>naked oat<br>Modern var. * |
|-------------------|---------------------|-------|-----|-----|-------------|-------|-------|-------|---------------------------------------|
|                   |                     |       |     |     | Shetland    |       |       |       |                                       |
|                   |                     |       |     |     | Wild oat    | Tiree | Grey  | Black |                                       |
| Kernel.           | Wt of 1000.         | grms. | ... | ... | 7.92        | 10.68 | 11.2  | 9.94  | 28.06                                 |
| Kernel.           | Percentage in grain | ...   | ... | ... | 50.1        | 72.2  | 68.7  | 71.8  | —                                     |
| Moisture          | ...                 | ...   | ... | ... | 11.2        | 12.3  | 14.8  | 16.3  | 13.6                                  |
| <b>Dry kernel</b> |                     |       |     |     |             |       |       |       |                                       |
| *Protein crude    | ...                 | ...   | ... | ... | 15.69       | 17.18 | 17.82 | 16.12 | 14.82                                 |
| Oil crude         | ...                 | ...   | ... | ... | 12.87       | 9.39  | 9.67  | 9.41  | 8.34                                  |
| Carbohydrate      | ...                 | ...   | ... | ... | 64.88       | 69.60 | 69.47 | 70.54 | 73.14                                 |
| Fibre             | ...                 | ...   | ... | ... | 4.00        | 1.39  | 1.52  | 1.60  | 1.50                                  |
| Ash               | ...                 | ...   | ... | ... | 2.56        | 2.44  | 2.52  | 2.33  | 2.20                                  |

\* Protein = % nitrogen  $\times 6.25$ .

#### *Proportion of whole grain in sample.*

The proportion of whole grain in the samples in 1909 varied from 78.2 to 98.5 %, the average being 90.8 %; in 1910 from 76.8 to 96.8 %, the average being 88.9 %; in 1911 from 89.1 to 99.7 %, the average being 96.1 %. The variation found from year to year, in the proportion of whole grain in the samples, was considerable, and it is attributed mainly to the result of the threshing and winnowing. The proportion in samples of the same variety also fluctuated to such an extent that it was not possible to establish any connection between this property and variety.

A system of tabulation of the results of the analyses of the grain of such a large number of oats had to be adopted. One was tempted to

<sup>1</sup> Sinclair, John, *Statistical Account of Scotland*, 1792, numerous references. Gerarde, John, *The Herbal of General History of Plants*, 1597, p. 68. Lindley, John, *Synopsis of British Flora*, 1849, p. 310. Ramsay, John, *Scotland and Scotsman in the Eighteenth Century*, 1888, 2, p. 196. Aberdeen, Earl of, *Collection of History of the Shires of Aberdeen and Banff*, 1543. Fitzherbert, Master, *The book of Husbandry from the 1534 edition*, 1883, p. 23. Prothero, R. E., *English Farming past and present*, 1912, p. 9. Rogers, J. E. T., *A History of Agriculture and prices in England*, 1886, 1, pp. 26 and 187.

<sup>2</sup> Lawson, Peter and Son, *Vegetable products of Scotland*, 1836, p. 94. Wilson, A. Stephen, *A bushel of Corn*, 1883, p. 144. De Candolle, A., *Origin of Cultivated Plants*, 1884, p. 273. Low, David, *Elements of Practical Agriculture*, 1834, p. 248. *Encyclopædia Britannica*, Article on Oats.

try and make a general classification of oats, but on working out the details of a scheme, there appeared to be so many sub-divisions, that the idea was abandoned. Several classifications<sup>1</sup> of oat grain have been published. The method which has been followed in tabulating the results in the present case is shown in Table VIII, pp. 382-385. Colour, weight of kernel, and proportion of kernel in the grain (thickness of husk) formed the principal basis. Sub-divisions into open and one sided inflorescence; early, medium, or late; grain and straw producing varieties, can be made from the data supplied in the table. The oats in each group are arranged in ascending order of the weight of kernel.

The grouping is as follows:

- White grain. 1. Thin husk (*a*) Small kernel weighing up to 21 grams per 1000 kernels.  
                   (*b*) Medium kernel weighing from 22 to 25 grams per 1000 kernels.  
                   (*c*) Large kernel weighing from 26 grams upwards per 1000 kernels.  
 2. Medium husk, medium and large kernels.  
 3. Thick husk, large kernels.

Yellow Grain. Thin husk, medium and large kernels.

- Black and Grey Grain. 1. Thin husk, small, medium and large kernels.  
 2. Thick husk, small, medium and large kernels.

Thin husk is taken to include grain containing 75 % or over; medium husk 73 to 74 %; thick husk up to 72 % of kernel in the grain.

The composition of the dry kernel and the percentage of water at the time when the analysis was made are given for each variety.

Analysis of the grain was also made, but the results are not included in Table VIII.

Before considering the different points in connection with Table VIII, reference is first made to some relationships which are brought out by averaging the analyses of the members of each group according to the size of the kernel. For this purpose the white grains with thin husks are taken. The result is shown in Table IX, p. 386.

These figures show that as the kernel increases in size, there is a decrease in the proportion of husk in the grain, the oil and fibre diminish, while the carbohydrates, the yield per acre of grain, and the proportion of grain to grain and straw, increase. The nitrogen does not appear to

<sup>1</sup> De Vries, H., *Species and Varieties, their origin and mutation*, p. 400. Morton's *Encyclopaedia of Agriculture*, 2, Article on Oats. *Encyclopaedia of American Agriculture*, Article on Oats. Wilson, A. Stephen, *A bushel of Corn*, Chap. VIII, 1883, p. 110.



[illegible]

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Table VIII (continued).

| Variety                                                                                                          | Country of Origin | Indurascence of open or one-sided | Weight of 1000 kernels, "air dry," grs. | Kernel in grain at time of analysis, per centage | Water percentage | Percentage composition of kernel "dry" |       |                |       |       | Weight of 1000 grains "air dry," grms. | Weight per bushel "dressed" grain, lbs. | Yield per acre in lbs. |       | Proportion of grain to grain and straw % |
|------------------------------------------------------------------------------------------------------------------|-------------------|-----------------------------------|-----------------------------------------|--------------------------------------------------|------------------|----------------------------------------|-------|----------------|-------|-------|----------------------------------------|-----------------------------------------|------------------------|-------|------------------------------------------|
|                                                                                                                  |                   |                                   |                                         |                                                  |                  | Protein                                | Oil   | Carbo- hydrate | Fibre | Ash   |                                        |                                         | Grain                  | Straw |                                          |
| Korax Husk<br>e's Progress<br>und<br>...<br>Hungarian<br>headed Giant<br>...<br>...<br>...<br>Average            | U.S.A.            | open                              | 21.62                                   | 12.37                                            | 13.50            | 8.15                                   | 74.90 | 1.41           | 2.04  | 29.44 | 37.0                                   | 2893                                    | 4704                   | 38.1  |                                          |
|                                                                                                                  | U.S.A.            | open                              | 22.02                                   | 14.25                                            | 13.60            | 9.20                                   | 72.85 | 1.70           | 2.25  | 29.50 | 36.5                                   | 1995                                    | 4751                   | 39.6  |                                          |
|                                                                                                                  | Holland           | open                              | 22.34                                   | 13.30                                            | 16.93            | 7.69                                   | 71.53 | 1.94           | 2.25  | 30.32 | 39.0                                   | 2200                                    | 4340                   | 34.6  |                                          |
|                                                                                                                  | Holland           | open                              | 23.08                                   | 11.98                                            | 14.25            | 8.72                                   | 73.61 | 1.36           | 2.06  | 30.86 | 32.6                                   | 2240                                    | 4240                   | 33.7  |                                          |
|                                                                                                                  | Hungary           | open                              | 23.74                                   | 14.26                                            | 14.30            | 8.02                                   | 73.93 | 1.35           | 2.20  | 31.06 | 39.5                                   | 2340                                    | 3990                   | 34.0  |                                          |
|                                                                                                                  | Hungary           | closed                            | 24.82                                   | 13.65                                            | 15.33            | 8.90                                   | 72.57 | 1.37           | 2.03  | 33.70 | 40.0                                   | 2388                                    | 4012                   | 34.1  |                                          |
|                                                                                                                  | Poland            | intermediate                      | 29.94                                   | 12.48                                            | 15.33            | 8.90                                   | 72.57 | 1.35           | 2.20  | 40.78 | 40.0                                   | 2388                                    | 4012                   | 34.1  |                                          |
|                                                                                                                  | England           | open                              | 32.54                                   | 13.15                                            | 17.00            | 8.48                                   | 73.16 | 1.35           | 2.19  | 43.90 | 39.5                                   | 2560                                    | 4832                   | 34.6  |                                          |
|                                                                                                                  | England           | open                              | 32.54                                   | 13.15                                            | 17.00            | 8.48                                   | 73.16 | 1.35           | 2.19  | 43.90 | 39.5                                   | 2560                                    | 4832                   | 34.6  |                                          |
|                                                                                                                  | Average           | ...                               | 25.01                                   | 13.02                                            | 14.99            | 8.27                                   | 73.02 | 1.55           | 2.17  | 33.81 | 38.0                                   | 2490                                    | 4455                   | 35.7  |                                          |
| Dorax Husk<br>...<br>...<br>...<br>...<br>...<br>...<br>...<br>Average                                           | England           | intermediate                      | 28.58                                   | 12.18                                            | 12.85            | 8.75                                   | 74.94 | 1.61           | 1.85  | 37.93 | 40.0                                   | 2984                                    | 4036                   | 40.0  |                                          |
|                                                                                                                  | England           | open                              | 29.22                                   | 12.48                                            | 13.20            | 7.98                                   | 75.24 | 1.63           | 2.05  | 38.42 | 42.0                                   | 2880                                    | 4421                   | 39.3  |                                          |
|                                                                                                                  | England           | closed                            | 30.56                                   | 14.29                                            | 17.50            | 6.10                                   | 72.82 | 1.31           | 2.12  | 42.74 | 39.0                                   | 2020                                    | 4120                   | 32.9  |                                          |
|                                                                                                                  | England           | open                              | 30.76                                   | 12.67                                            | 15.75            | 8.12                                   | 73.74 | 1.37           | 2.16  | 44.00 | 40.5                                   | 2404                                    | 3552                   | 40.3  |                                          |
|                                                                                                                  | England           | closed                            | 32.02                                   | 12.64                                            | 17.00            | 6.13                                   | 73.74 | 1.37           | 2.16  | 44.00 | 40.5                                   | 2404                                    | 3552                   | 40.3  |                                          |
|                                                                                                                  | England           | closed                            | 32.02                                   | 12.64                                            | 17.00            | 6.13                                   | 73.74 | 1.37           | 2.16  | 44.00 | 40.5                                   | 2404                                    | 3552                   | 40.3  |                                          |
|                                                                                                                  | England           | closed                            | 32.02                                   | 12.64                                            | 17.00            | 6.13                                   | 73.74 | 1.37           | 2.16  | 44.00 | 40.5                                   | 2404                                    | 3552                   | 40.3  |                                          |
|                                                                                                                  | England           | closed                            | 32.02                                   | 12.64                                            | 17.00            | 6.13                                   | 73.74 | 1.37           | 2.16  | 44.00 | 40.5                                   | 2404                                    | 3552                   | 40.3  |                                          |
|                                                                                                                  | England           | closed                            | 32.02                                   | 12.64                                            | 17.00            | 6.13                                   | 73.74 | 1.37           | 2.16  | 44.00 | 40.5                                   | 2404                                    | 3552                   | 40.3  |                                          |
|                                                                                                                  | Average           | ...                               | 30.23                                   | 12.85                                            | 15.33            | 6.94                                   | 74.13 | 1.46           | 2.09  | 40.88 | 40.0                                   | 2443                                    | 4154                   | 37.0  |                                          |
| Tux Husk<br>w Hungarian<br>w Tharian<br>w Pfaffbacher<br>n Giant<br>onite<br>an Lentewitz<br>t Yellow<br>Average | Hungary           | closed                            | 21.06                                   | 13.07                                            | 11.50            | 9.28                                   | 75.50 | 1.65           | 2.07  | 38.46 | 34.5                                   | 2033                                    | 4947                   | 29.1  |                                          |
|                                                                                                                  | Hungary           | closed                            | 22.62                                   | 13.51                                            | 11.50            | 9.28                                   | 75.50 | 1.65           | 2.07  | 38.46 | 34.5                                   | 2033                                    | 4947                   | 29.1  |                                          |
|                                                                                                                  | Hungary           | open                              | 22.74                                   | 13.15                                            | 14.31            | 8.70                                   | 76.00 | 1.56           | 2.02  | 39.20 | 37.0                                   | 2053                                    | 4147                   | 30.0  |                                          |
|                                                                                                                  | Hungary           | closed                            | 23.18                                   | 13.17                                            | 14.31            | 8.70                                   | 76.00 | 1.56           | 2.02  | 39.60 | 36.5                                   | 2493                                    | 4513                   | 35.6  |                                          |
|                                                                                                                  | Hungary           | open                              | 23.44                                   | 13.02                                            | 13.92            | 8.37                                   | 75.00 | 1.45           | 2.06  | 30.78 | 36.5                                   | 2440                                    | 4090                   | 37.6  |                                          |
|                                                                                                                  | Hungary           | open                              | 23.44                                   | 13.15                                            | 13.70            | 8.43                                   | 74.38 | 1.37           | 2.12  | 31.26 | 39.0                                   | 2592                                    | 4056                   | 39.0  |                                          |
|                                                                                                                  | Hungary           | open                              | 23.44                                   | 13.15                                            | 13.70            | 8.43                                   | 74.38 | 1.37           | 2.12  | 31.26 | 35.0                                   | 2190                                    | 4160                   | 34.5  |                                          |
|                                                                                                                  | Hungary           | open                              | 23.44                                   | 13.15                                            | 13.70            | 8.43                                   | 74.38 | 1.37           | 2.12  | 31.26 | 35.0                                   | 2190                                    | 4160                   | 34.5  |                                          |
|                                                                                                                  | Hungary           | open                              | 23.44                                   | 13.15                                            | 13.70            | 8.43                                   | 74.38 | 1.37           | 2.12  | 31.26 | 35.0                                   | 2190                                    | 4160                   | 34.5  |                                          |
|                                                                                                                  | Average           | ...                               | 23.07                                   | 13.58                                            | 13.22            | 8.35                                   | 74.55 | 1.53           | 2.05  | 30.53 | 35.3                                   | 2371                                    | 4418                   | 35.0  |                                          |
| Less Probestier<br>...<br>...<br>...<br>...<br>...<br>...<br>Average                                             | Sweden            | open                              | 26.26                                   | 14.27                                            | 13.41            | 7.18                                   | 75.60 | 1.57           | 1.95  | 34.18 | 41.5                                   | 2483                                    | 4227                   | 37.0  |                                          |
|                                                                                                                  | Sweden            | open                              | 26.26                                   | 14.27                                            | 13.41            | 7.18                                   | 75.60 | 1.57           | 1.95  | 34.18 | 41.5                                   | 2483                                    | 4227                   | 37.0  |                                          |
|                                                                                                                  | Sweden            | open                              | 26.40                                   | 14.03                                            | 12.94            | 6.98                                   | 76.10 | 1.52           | 1.93  | 34.66 | 40.0                                   | 2966                                    | 3712                   | 42.1  |                                          |
|                                                                                                                  | Sweden            | open                              | 26.40                                   | 14.03                                            | 12.94            | 6.98                                   | 76.10 | 1.52           | 1.93  | 34.66 | 40.0                                   | 2966                                    | 3712                   | 42.1  |                                          |
|                                                                                                                  | Sweden            | open                              | 26.40                                   | 14.03                                            | 12.94            | 6.98                                   | 76.10 | 1.52           | 1.93  | 34.66 | 40.0                                   | 2966                                    | 3712                   | 42.1  |                                          |
|                                                                                                                  | Sweden            | open                              | 26.40                                   | 14.03                                            | 12.94            | 6.98                                   | 76.10 | 1.52           | 1.93  | 34.66 | 40.0                                   | 2966                                    | 3712                   | 42.1  |                                          |
|                                                                                                                  | Sweden            | open                              | 26.40                                   | 14.03                                            | 12.94            | 6.98                                   | 76.10 | 1.52           | 1.93  | 34.66 | 40.0                                   | 2966                                    | 3712                   | 42.1  |                                          |
|                                                                                                                  | Sweden            | open                              | 26.40                                   | 14.03                                            | 12.94            | 6.98                                   | 76.10 | 1.52           | 1.93  | 34.66 | 40.0                                   | 2966                                    | 3712                   | 42.1  |                                          |
|                                                                                                                  | Sweden            | open                              | 26.40                                   | 14.03                                            | 12.94            | 6.98                                   | 76.10 | 1.52           | 1.93  | 34.66 | 40.0                                   | 2966                                    | 3712                   | 42.1  |                                          |
|                                                                                                                  | Average           | ...                               | 26.87                                   | 13.94                                            | 13.30            | 7.18                                   | 75.55 | 1.57           | 1.93  | 35.47 | 40.1                                   | 2760                                    | 4129                   | 40.1  |                                          |

## Black and Grey Grain

|                   |              |       |       |       |       |       |       |      |      |       |      |      |      |      |
|-------------------|--------------|-------|-------|-------|-------|-------|-------|------|------|-------|------|------|------|------|
| Tux Husk          | ...          | 17-12 | 75-10 | 14-01 | 14-39 | 8-81  | 72-95 | 1-51 | 2-34 | 22-78 | 35-5 | 1900 | 4530 | 30-6 |
| Out               | open         | 19-38 | 73-28 | 13-35 | 14-43 | 8-38  | 73-00 | 1-73 | 2-26 | 25-74 | 34-0 | 2038 | 4120 | 31-6 |
| ck                | closed       | 22-26 | 78-70 | 13-82 | 15-00 | 8-64  | 72-50 | 1-54 | 2-32 | 28-58 | 37-5 | 1620 | 2560 | 38-8 |
| "Holland          | open         | 25-38 | 77-91 | 14-01 | 12-93 | 10-85 | 73-14 | 1-53 | 2-05 | 32-36 | 30-0 | 2180 | 4124 | 34-6 |
| "Winter           | open         | 26-04 | 78-49 | 11-00 | 13-13 | 8-20  | 74-84 | 2-10 | 1-73 | 33-16 | 33-0 | 2160 | 3280 | 34-7 |
| set Crown...      | "            | 32-92 | 78-91 | 13-96 | 12-37 | 9-36  | 74-13 | 1-64 | 2-10 | 41-70 | 39-5 | 2372 | 4208 | 39-0 |
| ck Winter...      | "            | 23-85 | 77-10 | 13-36 | 13-74 | 9-92  | 73-43 | 1-68 | 2-13 | 30-70 | 36-4 | 2060 | 3554 | 35-2 |
| Average           | "            |       |       |       |       |       |       |      |      |       |      |      |      |      |
| Tux Husk          | ...          | 18-20 | 71-10 | 13-64 | 14-68 | 7-53  | 73-74 | 1-76 | 2-29 | 25-58 | 39-5 | 2130 | 4290 | 33-2 |
| ck Beauty...      | closed       | 19-32 | 72-98 | 12-72 | 14-46 | 8-80  | 72-57 | 1-91 | 2-26 | 26-46 | 35-5 | 2370 | 4620 | 33-9 |
| the Black         | "            | 20-06 | 71-66 | 13-91 | 14-24 | 7-41  | 74-32 | 1-93 | 2-10 | 27-98 | 35-0 | 2530 | 4370 | 34-8 |
| ck Mesdag...      | open         | 20-82 | 72-36 | 13-77 | 17-76 | 8-28  | 69-83 | 1-87 | 2-26 | 28-74 | 40-0 | 2100 | 4160 | 34-4 |
| ck Tartarian      | closed       | 21-72 | 73-30 | 13-99 | 14-53 | 7-13  | 74-49 | 1-84 | 2-21 | 29-42 | 39-0 | 2518 | 4320 | 35-8 |
| ck Great Mogul    | "            | 23-04 | 73-66 | 14-44 | 13-31 | 9-16  | 73-32 | 1-80 | 2-07 | 31-52 | 39-0 | 2518 | 4320 | 35-8 |
| ck Great Mogul    | open         | 23-84 | 73-47 | 14-31 | 13-01 | 9-00  | 73-32 | 1-80 | 2-07 | 32-88 | 39-0 | 2660 | 3660 | 42-8 |
| ck Great Mogul II | "            | 24-46 | 71-65 | 13-21 | 11-97 | 9-94  | 73-08 | 2-07 | 1-64 | 34-14 | 35-5 | 2832 | 3688 | 43-4 |
| ck Bullhead       | "            | 24-60 | 72-72 | 13-88 | 15-10 | 8-92  | 73-45 | 2-00 | 1-93 | 33-82 | 39-0 | 2220 | 3160 | 37-0 |
| ck Bullhead       | "            | 25-48 | 72-73 | 14-08 | 11-86 | 9-13  | 72-20 | 1-51 | 1-27 | 35-02 | 40-5 | 2255 | 3167 | 37-3 |
| ck Bullhead       | closed       | 25-86 | 72-95 | 14-08 | 11-86 | 8-53  | 72-16 | 1-50 | 1-23 | 35-42 | 40-5 | 2255 | 3167 | 37-3 |
| ck Bullhead       | intermediate | 28-62 | 73-68 | 13-08 | 15-35 | 8-55  | 72-16 | 1-50 | 1-23 | 38-34 | 39-0 | 2460 | 2660 | 38-9 |
| ck Bullhead       | open         | 32-84 | 73-52 | 13-08 | 17-00 | 5-75  | 73-18 | 1-89 | 2-18 | 38-78 | 40-0 | 2760 | 3696 | 42-7 |
| Average           | "            | 24-09 | 72-55 | 13-74 | 14-56 | 7-82  | 73-65 | 1-84 | 2-13 | 33-34 | 38-8 | 2419 | 4073 | 37-5 |

## Miscellaneous

|    |     |       |       |       |       |       |       |      |      |       |      |      |      |      |
|----|-----|-------|-------|-------|-------|-------|-------|------|------|-------|------|------|------|------|
| ck | ... | 20-50 | 77-22 | 13-28 | 20-10 | 5-45  | 69-90 | 1-50 | 2-25 | 26-34 | 47-0 | 2570 | 4903 | 34-0 |
| ck | ... | 20-50 | 77-22 | 13-28 | 14-82 | 8-34  | 73-13 | 1-50 | 2-20 | 28-06 | 24-3 |      |      |      |
| ck | ... | 10-68 | 72-18 | 12-26 | 17-18 | 9-39  | 69-69 | 1-39 | 2-44 | 14-78 |      |      |      |      |
| ck | ... | 7-92  | 50-06 | 11-20 | 15-69 | 12-87 | 64-88 | 4-00 | 2-56 | 15-84 |      |      |      |      |
| ck | ... | 11-20 | 68-70 | 10-39 | 17-82 | 8-97  | 69-47 | 1-52 | 2-32 | 15-78 |      |      |      |      |
| ck | ... | 9-94  | 71-80 | 16-39 | 16-12 | 9-41  | 70-54 | 1-00 | 2-33 | 13-84 |      |      |      |      |

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show any connection either with the size of the kernel, or with the oil, but, as will appear later, the nitrogen is a very variable constituent and the present data may be insufficient to bring out any point.

Except for the proportion of kernel in the grain, the above relationships invariably hold good with all the types.

Table IX. *Shows the relationship of size with the yield and composition of the grain.*

| Wt of<br>1000<br>kernels<br>"air-dry"<br>grms. | Per-<br>centage<br>kernel<br>in grain | Percentage composition of kernel<br>"dry" |      |                   |       |      | Yield per acre,<br>lbs. |       | Proportion<br>of grain<br>to grain<br>and straw<br>percentage |
|------------------------------------------------|---------------------------------------|-------------------------------------------|------|-------------------|-------|------|-------------------------|-------|---------------------------------------------------------------|
|                                                |                                       | Protein                                   | Oil  | Carbo-<br>hydrate | Fibre | Ash  | Grain                   | Straw |                                                               |
| 20.57                                          | 75.79                                 | 14.76                                     | 8.89 | 72.59             | 1.56  | 2.20 | 2276                    | 4614  | 33.2                                                          |
| 24.01                                          | 75.74                                 | 13.50                                     | 8.20 | 74.59             | 1.55  | 2.16 | 2458                    | 4252  | 36.8                                                          |
| 27.67                                          | 75.95                                 | 13.56                                     | 7.49 | 75.38             | 1.48  | 2.09 | 2634                    | 4118  | 39.4                                                          |
| 31.58                                          | 76.65                                 | 14.39                                     | 6.87 | 75.23             | 1.41  | 2.10 | 2687                    | 4057  | 40.8                                                          |

#### *Parental types.*

White grain. 1. Thin husks. In this group the smaller kernels are represented by the Sandy type, the medium including some of the smaller kernels, by the Potato type and the large kernels by the New Abundance type. Sandy is a long kernel. Potato is a plump oval kernel and is typical of the majority of the thin husked grains, most of which have come into existence by a process of selection. The newer varieties produced by cross-breeding, such as Victory, Garriss, Crown, etc., included in this group should each be considered separately.

2. Medium husk. Medium and large kernels. Represented by Universal and Polish, the newer varieties by Hero, Glebe, etc.

3. Thick husk. Large kernel. Represented by Storm King and Tartar King. The newer varieties by Yelder, Record, Leader, etc.

Yellow grain. Thin husk. Medium kernel. Represented by Golden Giant and Golden Yellow. Large kernel. Represented by Colossal and Golden Rain.

Black and Grey grain. 1. Thin husk. Small medium and large kernels. Represented by Dun Oat and Grey Houdan. Winter oats are included in this group.\*

2. Thick husk. Small, medium and large kernels. Represented by Black Tartarian and Myrtle Black. The newer varieties by Supreme and Bountiful.

A summary of the grouping is given in Table X, p. 387.

Table X.

|                                        | Weight of 1000 kernels, "as is," in grain, grms. | Per-centage kernel in grain | Percentage composition of "dry" kernel |      |               |       |      | Yield per acre, lbs. |       | Proportion of grain to grain and straw percentage |
|----------------------------------------|--------------------------------------------------|-----------------------------|----------------------------------------|------|---------------|-------|------|----------------------|-------|---------------------------------------------------|
|                                        |                                                  |                             | Protein                                | Oil  | Carbo-hydrate | Fibre | Ash  | Grain                | Straw |                                                   |
| <i>White Grain:</i>                    |                                                  |                             |                                        |      |               |       |      |                      |       |                                                   |
| 1. Thin husk: (a) Small kernel ...     | 20.57                                            | 75.79                       | 14.76                                  | 8.89 | 72.50         | 1.56  | 2.20 | 2276                 | 4614  | 33.2                                              |
| " " (b) Medium " ...                   | 24.01                                            | 75.74                       | 13.50                                  | 8.20 | 74.38         | 1.55  | 2.16 | 2458                 | 4252  | 36.8                                              |
| " " (c) Large " ...                    | 27.67                                            | 75.95                       | 13.56                                  | 7.49 | 73.38         | 1.48  | 2.00 | 2634                 | 4118  | 39.4                                              |
| " " " " ...                            | 31.38                                            | 76.65                       | 14.39                                  | 6.87 | 75.23         | 1.41  | 2.10 | 2687                 | 4057  | 40.8                                              |
| 2. Medium husk, M. and L. kernel ...   | 25.01                                            | 73.98                       | 14.99                                  | 8.27 | 73.02         | 1.55  | 2.17 | 2490                 | 4485  | 35.7                                              |
| 3. Thick husk, Large kernel ...        | 30.23                                            | 72.48                       | 15.38                                  | 6.94 | 74.13         | 1.46  | 2.09 | 2443                 | 4154  | 37.0                                              |
| <i>Yellow Grain:</i>                   |                                                  |                             |                                        |      |               |       |      |                      |       |                                                   |
| Thin husk: (a) Medium kernel ...       | 23.07                                            | 75.55                       | 13.22                                  | 8.35 | 74.85         | 1.53  | 2.05 | 2371                 | 4418  | 35.9                                              |
| " " (b) Large " ...                    | 26.87                                            | 76.42                       | 13.30                                  | 7.48 | 75.75         | 1.43  | 2.04 | 2749                 | 4129  | 40.1                                              |
| <i>Black and Grey Grain:</i>           |                                                  |                             |                                        |      |               |       |      |                      |       |                                                   |
| 1. Thin husk, S. M. and L. kernel ...  | 23.85                                            | 77.4                        | 13.74                                  | 9.02 | 73.43         | 1.68  | 2.13 | 2060                 | 3854  | 35.2                                              |
| 2. Thick husk, S. M. and L. kernel ... | 24.09                                            | 72.55                       | 14.56                                  | 7.82 | 73.65         | 1.84  | 2.13 | 2449                 | 4073  | 37.6                                              |



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#### *Old and new varieties.*

Potato and Sandy are the best known representatives of the old varieties. A characteristic feature of these oats is the relative large number of spikelets in the ear, each spikelet contains usually only singles and doubles. The grains are small or medium size and have a thin husk. The proportion of grain to grain and straw is low.

The newer varieties usually have fewer spikelets in the ear but each spikelet has a larger number of developed grains and contains singles, doubles, trebles and sometimes quadruples. For this reason samples of grain from these varieties are not as uniform in size, or in composition except perhaps under drastic dressing, and winnowing, compared with that of the old varieties. The grains are usually medium or large and more often contain thick husks. The proportion of grain to grain and straw is high.

The above differences which appear to exist between old and new varieties are not of a permanent kind. Among the first signs of degeneration in a variety is the production of fewer spikelets with fewer developed grains in the spikelet, while a rejuvenated old variety usually contains an increased proportion of spikelets with a larger number of fully developed grains. Grain producing power appears to be largely a matter of the cultural conditions under which the crop has been acclimatised.

#### *Grain and straw producing varieties.*

The grain producing varieties yield a larger proportion of grain to total crop than the straw producing varieties. The latter tiller more. For convenience they may be grouped as follows:

1. Straw producers—the ratio of grain to grain and straw varies up to about 33 %.
2. Medium grain producers—from about 34 to 37 %.
3. Grain producers—from 38 % and over.

#### *Early and late varieties.*

Wright<sup>1</sup> has shown that the early varieties as a rule consist of the grain producing varieties while the late varieties are generally the straw producing varieties. Tillering<sup>2</sup> power seems to be connected

<sup>1</sup> Wright, R. Patrick, "Experiment on the comparative merits of Varieties of Oats," *West of Scotland Ag. College Bull.* 12, 1900.

<sup>2</sup> McAlpine, A. N., *Bull.* 12, *West of Scotland Ag. College*, Section on Botanical Characters of Oats.

with both this and the previously considered property. Of all the varieties the Sixty-day oat is the earliest. It is a small kernel, thin husk, poor in oil, but exceptionally rich in nitrogen. The yields of grain recorded for this oat are very unreliable, being ripe first it suffered considerably from birds.

*Winter oats.*

These oats are poorly represented in the table. The grain is medium or large, possesses a thin husk and is exceptionally rich in oil. They are early oats.

*Nutritive value of oat grain.*

For evidence of the nutritive value of oats reference need only be made to the fact that at an early period and even in out-of-the-way places in Scotland at the present time, oatmeal formed the staple food of the population. As an example, in the *Statistical Account of Scotland* published towards the end of the eighteenth century, observations such as the following occur—Oatmeal is the principal food of the common people<sup>1</sup>, Oatmeal the general food of the Country<sup>1</sup>. Loudon's *Encyclopaedia*<sup>2</sup> dealing with the same period says: "Farm servants in their food live much in the same simple way as their forefathers. Oatmeal forms the principal basis, or part of their sustenance. They have it regularly to breakfast and to supper made into a pottage with a small allowance of butter milk. At dinner they eat it in bread, in addition to a thin kale or kind of soup made with barley broth, intermixed with greens and pot herbs. To this they add potatoes and at times fish of different kinds, seldom wheat bread and still more rarely butcher meat. On this feeding they can go through their labour without feeling oppressed and enjoy a state of health which is seldom interrupted." Another more detailed description is given, on p. 1179 of the same volume.

In England according to Rogers<sup>3</sup> when writing of the conditions of agriculture in the thirteenth century, wheat had been the customary food of the country from the earliest of times, while oats were almost universally grown for cattle, but oatmeal was made for the broth or porridge of the house. However Headricks<sup>4</sup> writing of the position

<sup>1</sup> Sinclair, John, *Statistical Account of Scotland*, 1792, 3, p. 233; 4, p. 152.

<sup>2</sup> Loudon's *Encyclopaedia of Agriculture*, 1883, pp. 1179 and 1190.

<sup>3</sup> Rogers, J. E. T., *A History of Agriculture and Prices in England*, pub. 1886, 1, pp. 28 and 187.

<sup>4</sup> Headricks, James, *General view of the Agriculture of Angus (Forfarshire)*, 1813.

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several centuries later states that oatmeal is as much used in some parts of England as in any part of Scotland. That this seems to be the case is shown in a publication<sup>1</sup> issued by the Board of Agriculture in 1794, in which Basil Qualye, describing the agriculture of the Isle of Man, remarks that oats were in general cultivation especially on the Upland farms, and the meal produced from the grain forms a considerable part of the diet of the labouring classes. Similar confirmation is found in the same volume in the section dealing with the agriculture of Lancashire and Northumberland. Frequent reference to the value of oats for meal purposes also occurs.

At the present time five-sixths<sup>2</sup> of the total consumption of oat grain, exclusive of the seed, is used as cattle food in the United Kingdom. About 10 % of the grain is imported. Wood<sup>3</sup> estimates that the cereal food just prior to the outbreak of the great war contributed over one-third of the work producing power of the population of the British Isles, towards which oatmeal contributed only 1.6 %. No figures showing the relative consumption of oat grain as cattle food and as oatmeal, for Scotland, seems to have been published.

#### *Composition and feeding value of oatmeal.*

A feeding experiment with pigs was carried out with oatmeal containing a high compared with a low oil content. Potato oat was taken as representative of the former and Storm King of the latter. Forty pigs were available and after a preliminary experiment lasting two weeks, four were eliminated. The remaining 36 pigs were arranged into two groups of 18, and placed four pigs to a pen. The pigs were fed for 13 weeks, commencing on the 15th of June, on the following rations:

For the first month

*Lot A* received 2½ lbs. oatmeal (calculated from dry state) of Potato oat and 1½ gal. whey per head per day.

*Lot B* received 2½ lbs. oatmeal (calculated from dry state) of Storm King and 1½ gal. whey per head per day.

The meal was increased monthly by ½ lb. per head per day and ¼ gal. whey each.

Each pig was weighed at the end of each week throughout the experi-

<sup>1</sup> Qualye, Basil, *Tracts on Agriculture*, pub. 1794, by Board of Agri., Isle of Man, p. 35.  
Holt, John, *Lancashire*, p. 28. Baily and Cullen, *Northumberland*, p. 33.

<sup>2</sup> International Institute of Agriculture, *Statistical notes on Cereals*, 1917, No. 6.

<sup>3</sup> Wood, T. B., *The Nation's Food Supply in Peace and War*, 1917, p. 9.

ment. The composition of the meals and the results of the feeding are given in the following tables:

Table XI. *Composition of the meal.*

|                  |     | Potato oat kernel |       |         | Storm King oat kernel |       |         |
|------------------|-----|-------------------|-------|---------|-----------------------|-------|---------|
|                  |     | Air dry           | Dry   | Oatmeal | Air dry               | Dry   | Oatmeal |
| Moisture ...     | ... | 11.68             | —     | —       | 14.70                 | —     | —       |
| Protein ...      | ... | 12.62             | 14.75 | 14.54   | 14.18                 | 16.62 | 16.80   |
| Oil... ..        | ... | 8.30              | 9.72  | 8.96    | 5.31                  | 6.52  | 5.76    |
| Carbohydrate ... | ... | 61.20             | 71.78 | 73.02   | 62.43                 | 73.20 | 73.92   |
| Fibre ...        | ... | 1.33              | 1.56  | 1.35    | 1.51                  | 1.77  | 1.35    |
| Ash ...          | ... | 1.87              | 2.49  | 2.13    | 1.87                  | 2.49  | 2.17    |

Table XII. *Results of the feeding.*

| Lot | Initial weight of<br>18 pigs<br>lbs. | Weight after 13<br>weeks feeding<br>lbs. | Average daily gain<br>per pig<br>lbs. |
|-----|--------------------------------------|------------------------------------------|---------------------------------------|
| A   | 1421                                 | 3864                                     | 1.49                                  |
| B   | 1419                                 | 3793                                     | 1.44                                  |

Difference in favour of A ... 71

For the first three weeks of the experiment the pigs receiving the oatmeal with a low oil but with a high nitrogen content, produced a slightly higher daily increase. Afterwards, and until the end of the experiment, the meal with the high oil content, produced the greater daily increase. The final result is so close that the figures could quite well come within the limits of the experimental error.

A similar experiment was carried out with 50 black faced Waddler Hoggets separated into two lots of 25. One lot received 15 lbs. roots and  $\frac{1}{2}$  lb. Potato oatmeal per 100 lbs. live weight per head per day. The other lot received the Storm King meal.

The experiment only lasted six weeks and the final result was in the same direction as that with the pigs.

#### *Mealing power of oat grain.*

In the above experiment five tons each of Potato, a thin husked grain, and of Storm King, a thick husked grain, were used. They were milled in one ton lots. The proportion of meal obtained is given in Table XIII, p. 392.

The yield of oatmeal from kiln dried grain is directly proportional to the percentage of kernel in the grain. A high water content reduces the yield of meal and a low water content produces the opposite effect.

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The various factors which influence the mealing power of oats have been admirably summarised by Greig and Findlay<sup>1</sup>.

Table XIII.

| Variety    | Weight<br>per<br>bushel<br>lbs. | Weight<br>of 1000<br>kernels<br>grms. | Per-<br>centage<br>kernel<br>in grain | Yield of oatmeal<br>percentage |                     | Meal<br>seeds<br>per-<br>centage | Rough<br>seeds<br>(husk)<br>per-<br>centage | Oat<br>dust<br>per-<br>centage |
|------------|---------------------------------|---------------------------------------|---------------------------------------|--------------------------------|---------------------|----------------------------------|---------------------------------------------|--------------------------------|
|            |                                 |                                       |                                       | original<br>grain              | kiln dried<br>grain |                                  |                                             |                                |
| Potato ... | 44.5                            | 22.50                                 | 76.35                                 | 58.6                           | 71.2                | 19.2                             | 2.6                                         | 7.0.                           |
| Storm King | 42.4                            | 31.56                                 | 65.82                                 | 51.5                           | 61.9                | 27.9                             | 2.6                                         | 7.6                            |

#### *Water in oatmeal.*

In these experiments the average percentage of water in oatmeal at the time of milling was 1.79 %, and in the original grain 14.6 %. The oatmeal until required was stored in sacks, the weight increased appreciably due to the absorption of water. The rate of absorption of water dating from June 15th, was as follows:

| After 4 days 2.96 % water in oatmeal |    |    |        |    |    |
|--------------------------------------|----|----|--------|----|----|
| ..                                   | 11 | .. | 3.35 % | .. | .. |
| ..                                   | 24 | .. | 4.73 % | .. | .. |
| ..                                   | 38 | .. | 5.76 % | .. | .. |
| ..                                   | 50 | .. | 6.37 % | .. | .. |

The fat in oatmeal also undergoes change with storage, see p. 369.

Colour, flavour, water absorbing powers and keeping qualities, are the factors by which "quality" in oatmeal is judged. According to millers, kiln-drying brings out the flavour, and the opinion is general that the oil, is the principal factor which contributes the flavour. The oil content cannot, however, be the only factor as the percentage of oil in a sample of Scotch oatmeal, and in oatmeal made from Plate oats, was found to be 11.2 % for the former, and 10.8 % for the latter, both of which figures are high. One sample was considered to be of good and the other of poor quality. Scotch oats are moister and require longer kiln drying, than Plate oats.

The following table shows the proportion of water soluble nitrogen compounds, phosphates, and potash salts in the two samples. The Scotch oats contain a larger proportion of water soluble, nitrogen and mineral compounds.

<sup>1</sup> Greig, R. B. and Findlay, W. M., "The Milling properties of Oats," *Journ. Bd. of Agriculture*, 1907, 19, No. 5.

Table XIV.

| Dry meal                                                           | Oatmeal           |                  |
|--------------------------------------------------------------------|-------------------|------------------|
|                                                                    | Scotch oats<br>"o | Plate oats<br>"o |
| Oil ... ..                                                         | 11.2              | 10.8             |
| Nitrogen, total ... ..                                             | 2.16              | 2.06             |
| Nitrogen, water sol., percentage of total ...                      | 15.7              | 9.32             |
| Ash, total ... ..                                                  | 2.05              | 1.79             |
| Ash, water sol., percentage of total ...                           | 42.3              | 38.3             |
| Phosphoric acid, $P_2O_5$ , total ... ..                           | 1.16              | 0.85             |
| Phosphoric acid, $P_2O_5$ , water sol., percentage of total ... .. | 31.0              | 25.7             |
| Potash, $K_2O$ , total ... ..                                      | 0.769             | 0.465            |
| Potash, $K_2O$ , water sol., percentage of total                   | 44.3              | 61.3             |
| Percentage, phosphoric acid in ash ...                             | 56.5              | 47.9             |
| Percentage, water sol. phosphoric acid in ash                      | 17.5              | 12.2             |
| Percentage, potash in ash ... ..                                   | 37.5              | 26.0             |
| Percentage, water sol. potash in ash ...                           | 16.6              | 15.9             |
| Percentage phosphoric acid in sol. ash ...                         | 41.5              | 31.9             |
| Percentage potash in sol. ash ... ..                               | 39.3              | 41.6             |

*Composition of the husk and chaff of different varieties.*

The following table shows the variation found:

|                 | Chaff<br>"o | Husk<br>"n |
|-----------------|-------------|------------|
| Nitrogen ... .. | 0.48-0.95   | 0.15-0.50  |
| Fibre ... ..    | 16.80-19.4  | 30.1-36.0  |
| Ash ... ..      | 10.26-20.2  | 4.7-6.5    |

*Proportion of embryo (germ) in kernel.*

The proportion of embryo in the kernels of several of the varieties examined varied as follows: Potato, medium sized kernel, 3.8%; Storm King, large kernel, 2.6%; Beseler's prolific, large kernel, 3.7%; Native Oat, small kernel, 2.6%. Compared with the whole kernel the endosperm was found to contain 93.1% of the ash, 87.7% of the oil, 95.4% of the protein, and 93.3% of the phosphoric acid.

## CORRELATION OF SIZE WITH OTHER CHARACTERS OF THE GRAIN.

In Table IX, p. 386, a connection between the size and other characters of the grain of different varieties was shown to exist, the figures in the following table bring out this point more clearly. The figures are taken from the results of analyses of samples of dressed grain obtained from field experiments carried out in the south and south-western

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counties of Scotland. In arranging the table, the analysis and other data for each sample of grain were tabulated in ascending order of the weight of kernel commencing with the lightest and averages taken. The following result was obtained:

Table XV.

| Weight of 1000 kernels grms. | Kernel               |                      | Dry kernel  |                     |                 |                 |            | Weight per bushel of grain lbs. | Yield per acre |      | Ratio of grain to straw and straw per-centage | Number of cwt per acre |
|------------------------------|----------------------|----------------------|-------------|---------------------|-----------------|-----------------|------------|---------------------------------|----------------|------|-----------------------------------------------|------------------------|
|                              | in grain per-centage | moisture per-centage | Nitrogen    |                     | oil per-centage | ash per-centage | grain lbs. |                                 | straw lbs.     |      |                                               |                        |
|                              |                      |                      | per-centage | yield per acre lbs. |                 |                 |            |                                 |                |      |                                               |                        |
| 20.8                         | 72.0                 | 11.3                 | 2.75        | 49.6                | 8.20            | 2.15            | 37.6       | 1808                            | 5528           | 24.6 | 22                                            |                        |
| 23.0                         | 74.3                 | 12.1                 | 2.55        | 52.3                | 8.25            | 2.00            | 37.6       | 2051                            | 4127*          | 33.2 | 32                                            |                        |
| 25.0                         | 75.0                 | 12.3                 | 2.45        | 53.0                | 8.24            | 2.12            | 39.7       | 2163                            | 4873           | 30.7 | 35                                            |                        |
| 27.2                         | 75.5                 | 12.8                 | 2.26        | 55.0                | 8.23            | 2.05            | 40.9       | 2433                            | 4370           | 35.7 | 36                                            |                        |
| 29.0                         | 75.6                 | 13.5                 | 2.32        | 57.4                | 8.25            | 2.08            | 41.1       | 2473                            | 4063           | 37.9 | 36                                            |                        |

\* This figure is low, owing to low yields at some centres.

It is seen that with increase in the size of the grain there is a corresponding decrease in the proportion of husk, the percentage of nitrogen in the grain, and in the yield of straw per acre, whilst the yield per acre, of the grain, the weight per bushel, the ratio of grain to straw, the carbohydrate content, and the percentage of moisture in the grain, showed a progressive increase. The percentage of oil and ash remained stationary. Although the kernel becomes poorer in nitrogen as its size increases, the actual yield per acre of nitrogen increases, owing to the larger yield of grain.

The above table differs from that on p. 386 in that the relationships shown here are those produced from the effect on the grain of cultural conditions.

A consideration of the table at this stage, it was thought, provided a good starting point for taking up in some detail the various factors, apart from the influence of variety, which produce change in the composition and characters of the oat crop.

#### EARLY AND LATE SOWING.

The average result of five experiments have been taken. In each one the seed was sown in the months of January, February, March and April respectively. The figures are given in Table XVI following.

The January sowing gives the heavier grain and the thinner husk. The grain diminishes in size each month, that from the April sowing

being the smallest and it contained the thickest husk. The ash diminishes in the same order. The oil and the nitrogen do not appear to be affected.

Table XVI.

|                                         |     |     |     |     | Average of five experiments |          |       |       |
|-----------------------------------------|-----|-----|-----|-----|-----------------------------|----------|-------|-------|
|                                         |     |     |     |     | Date of sowing              |          |       |       |
|                                         |     |     |     |     | January                     | February | March | April |
| Kernel, wt of 1000. grms.               | ... | ... | ... | ... | 28.48                       | 28.22    | 28.06 | 27.34 |
| " percentage in grain                   | ... | ... | ... | ... | 73.97                       | 73.68    | 73.38 | 73.21 |
| <i>Dry kernel</i> : percentage nitrogen | ... | ... | ... | ... | 2.45                        | 2.07     | 1.90  | 2.11  |
| " " oil                                 | ... | ... | ... | ... | 8.22                        | 8.33     | 8.45  | 8.37  |
| " " ash                                 | ... | ... | ... | ... | 2.12                        | 2.01     | 1.96  | 1.93  |
| <i>Dry straw</i> : percentage, nitrogen | ... | ... | ... | ... | 0.29                        | 0.27     | 0.28  | 0.29  |
| " " phosphoric acid, $P_2O_5$           | ... | ... | ... | ... | 0.058                       | 0.046    | 0.043 | 0.040 |
| " " potash, $K_2O$                      | ... | ... | ... | ... | 1.72                        | 1.54     | 1.41  | 1.32  |
| " " lime, $CaO$                         | ... | ... | ... | ... | 0.62                        | 0.54     | 0.53  | 0.49  |

The crop from the April sown seed was in each experiment ripe last, whilst there was not much difference between the date of ripening of the other sowings. The crop from the early sown seed contained many blank spaces and being ripe first suffered more from damage by birds which fact depresses the yield of grain for these months.

The following table provides data bearing upon the relative development of the plant from the respective sowings. The figures are the averages of four experiments.

Table XVII.

|                                        |     |     |     |     | Average of four experiments |          |       |       |
|----------------------------------------|-----|-----|-----|-----|-----------------------------|----------|-------|-------|
|                                        |     |     |     |     | January                     | February | March | April |
| Weight in ozs. of 500 complete stems   | ... | ... | ... | ... | 75                          | 67       | 70    | 54    |
| Proportion of grain to grain and straw | ... | ... | ... | ... | 44                          | 45       | 46    | 50    |

From these figures it is evident that, provided a full crop could be grown, the early sown seed produces the largest yield of grain and straw per acre. The weather in the early months is very precarious for sowing, for germination, and for growth generally, but when once established the plant possesses advantages in that it develops a better root system compared with that of plants grown from later sown seed.

#### EFFECT OF MANURING.

According to the figures in Table XVIII which are the average results of an experiment carried out at five centres on soils in an average state of fertility, the effect of moderate dressings of manures on the compo-



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sition of the grain is comparatively slight. The grain from the plots receiving nitrate is slightly richer in nitrogen. The well-known effect of the application of nitrogen manures was also visible in the colour of the straw. The date of ripening of the crop for the respective plots did not vary within more than six days. Under less favourable soil and climatic conditions, the results, would in all probability have been more pronounced.

Table XVIII.

|                               | Nitrate<br>of<br>soda | Sulphate<br>of<br>potash | Super-<br>phosphate<br>of lime | Nitrate<br>and<br>super. | Un-<br>manured | Nitrate<br>and<br>potash | Super-<br>and<br>potash | Nitrate<br>super and<br>potash |
|-------------------------------|-----------------------|--------------------------|--------------------------------|--------------------------|----------------|--------------------------|-------------------------|--------------------------------|
| Kernel, weight of 1000. grms. | 20.12                 | 20.68                    | 20.58                          | 20.44                    | 20.20          | 20.28                    | 20.62                   | 20.48                          |
| „ percentage in grain...      | 74.52                 | 74.66                    | 74.64                          | 75.13                    | 74.29          | 74.92                    | 74.74                   | 74.76                          |
| Dry kernel:                   |                       |                          |                                |                          |                |                          |                         |                                |
| Nitrogen percentage ...       | 2.71                  | 2.59                     | 2.54                           | 2.67                     | 2.54           | 2.66                     | 2.52                    | 2.54                           |
| Oil „ ...                     | 8.34                  | 8.44                     | 8.46                           | 8.39                     | 8.41           | 8.32                     | 8.36                    | 8.36                           |
| Ash „ ...                     | 2.23                  | 2.27                     | 2.30                           | 2.29                     | 2.25           | 2.20                     | 2.28                    | 2.21                           |
| Dry straw:                    |                       |                          |                                |                          |                |                          |                         |                                |
| Nitrogen percentage ...       | 0.32                  | 0.31                     | 0.34                           | 0.32                     | 0.31           | 0.37                     | 0.31                    | 0.29                           |

The manures were applied at the following rate per acre, nitrate of soda 1 cwt., sulphate of potash  $\frac{3}{4}$  cwt., superphosphate 3 cwt.

#### INFLUENCE OF SEASON.

The grain of two varieties of oats, Potato and Sandy, grown at Kilmarnock, has been analysed yearly since 1908, and the average result for each year is given in Table XIX. The crops received an annual dressing of 2 cwt. of superphosphate, 2 cwt. of kainit or its equivalent and 1 cwt. of nitrate of soda per acre. See tables in Appendix for meteorological and soil conditions.

Table XIX.

| Year | Rainfall<br>inches | Length of<br>growing<br>period<br>days | Kernel                     |                        |                          | Percentages in dry kernel |      |      |
|------|--------------------|----------------------------------------|----------------------------|------------------------|--------------------------|---------------------------|------|------|
|      |                    |                                        | Weight<br>of 1000<br>grms. | Percentage<br>in grain | Water<br>per-<br>centage | Nitrogen                  | Oil  | Ash  |
| 1908 | 39.6               | 150                                    | 21.76                      | 76.12                  | 13.71                    | 2.41                      | 8.61 | 2.29 |
| 1909 | 40.9               | 154                                    | 21.50                      | 76.20                  | 12.77                    | 2.27                      | 8.98 | 2.23 |
| 1910 | 37.9               | 146                                    | 21.01                      | 76.01                  | 14.03                    | 2.30                      | 9.03 | 2.23 |
| 1911 | 36.0               | 143                                    | 21.78                      | 76.18                  | 13.24                    | 2.42                      | 8.39 | 2.19 |
| 1912 | 36.7               | 143                                    | 21.41                      | 75.35                  | 13.80                    | 2.26                      | 8.82 | 2.11 |
| 1913 | 33.6               | 135                                    | 20.20                      | 75.20                  | 11.60                    | 2.31                      | 8.92 | 2.23 |
| 1914 | 38.1               | 136                                    | 20.34                      | 75.38                  | 12.99                    | 2.45                      | 8.79 | 2.27 |
| 1915 | 32.5               | 139                                    | 20.91                      | 76.49                  | 13.39                    | 2.20                      | 9.29 | 2.12 |
| 1916 | 42.9               | 146                                    | 23.82                      | 76.50                  | 11.03                    | 2.74                      | 8.20 | 2.43 |

The 1916 crop was grown on newly ploughed up land, which had been under permanent pasture for a number of years. In this year the grain was heavier and the percentage of nitrogen higher than in any of the preceding years, while the oil was the lowest. The change produced in the size and composition of the grain in one year, by growing the crop on land newly ploughed up, compared with arable land in the previous years, is therefore greater than that produced from the effect of the climate in any one of the nine years covered by the experiment. The percentage variation is given in Table XXI, p. 398.

The influence of season upon the yield per acre of grain and straw is more marked as shown in the following figures. The figures are the average of 29 varieties grown annually at Kilmarnock.

Table XX.

|                                      |     |     |     |     |     | Yield per acre, lbs. |      |      |      |      |
|--------------------------------------|-----|-----|-----|-----|-----|----------------------|------|------|------|------|
|                                      |     |     |     |     |     | 1907                 | 1908 | 1909 | 1910 | 1911 |
| Grain                                | ... | ... | ... | ... | ... | 2648                 | 2325 | 2720 | 2651 | 2525 |
| Straw                                | ... | ... | ... | ... | ... | 4653                 | 3635 | 4642 | 3470 | 4081 |
| Ratio of grain to grain and straw, % | ... | ... | ... | ... | ... | 39.5                 | 38.9 | 37.1 | 37.1 | 38.2 |

The average ratio of grain to the total crop is remarkably uniform during the period in question.

#### INFLUENCE OF LOCALITY.

Samples of grain obtained from a number of varieties grown for several years on farms situated in the south and south-western counties of Scotland, were analysed. The same varieties were grown annually at all the farms. The average result of the analyses obtained for each farm is the figure taken as the basis for comparison. The height above sea-level and the length of the growing period were recorded in the majority of cases.

In order to indicate what has been the maximum change produced in the characters of the grain in one year, the difference between the centre with the lowest figure and the centre with the highest figure has been taken and the result expressed as a percentage of the lowest. The variation in the yield of grain and straw is not included. For information upon this point reference should be made to the *Bulletins* on oat experiments issued by Agricultural Colleges.

The average yields<sup>1</sup> of oats obtained in different parts of Scotland, are given as follows:

<sup>1</sup> *Board of Agriculture for Scotland, Agri. Statistics, 1914, 3, Pt II, p. 117*

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The yield per acre for the North and North-Western Counties is 33·08 bushels

|   |   |   |                        |   |   |       |   |
|---|---|---|------------------------|---|---|-------|---|
| " | " | " | North-Eastern          | " | " | 39·69 | " |
| " | " | " | Central                | " | " | 45·12 | " |
| " | " | " | South-Eastern          | " | " | 43·5  | " |
| " | " | " | West and South-Western | " | " | 40·02 | " |

The table below shows the maximum variation in the characters of the grain produced by locality. The year 1916, for reasons already stated, was not included in calculating the variation found at Kilmarnock.

Table XXI.

*This table shows the maximum variation in the grain from different centres in the years 1909, 1910 and 1911 in percentages.*

| Year                                                    | Kernel               |                      | Water | Dry kernel |      |      | Number of farms |
|---------------------------------------------------------|----------------------|----------------------|-------|------------|------|------|-----------------|
|                                                         | Weight of 1000 grms. | Pro-portion in grain |       | Nitrogen   | Oil  | Ash  |                 |
| 1908-1916                                               | 7·9                  | 1·7                  | 20·9  | 11·4       | 10·7 | 8·5  | Exp. Station    |
| 1909                                                    | 18·5                 | 3·1                  | 22·6  | 37·0       | 18·8 | 34·9 | 14              |
| 1910                                                    | 33·5                 | 6·7                  | 30·9  | 54·5       | 28·9 | 17·6 | 17              |
| 1911                                                    | 38·2                 | 7·8                  | 28·0  | 39·2       | 16·8 | 23·9 | 15              |
| Average composition of kernel for each year, percentage |                      |                      |       |            |      |      |                 |
| 1909                                                    | 26·26                | 74·73                | 12·51 | 2·31       | 8·28 | 2·02 |                 |
| 1910                                                    | 24·38                | 75·20                | 11·27 | 2·28       | 8·54 | 2·08 |                 |
| 1911                                                    | 24·52                | 74·2                 | 13·40 | 2·73       | 7·71 | 2·07 |                 |

The 1911 figures contain five centres situated in the south of England and Wales. This year therefore includes climatic and soil conditions not represented in the two preceding years. The variation found, is of course limited in its application to the cultural conditions under which the crops were growing. But as there were centres in each year situated from sea level up to an elevation of, and sometimes over 1000 ft., the results can be taken to indicate the type of variation commonly occurring in any year, in this part of Scotland, also at one centre over a number of years. By using "dressed" instead of "undressed" grain, the variation is in all probability below rather than above that which actually occurs.

The analyses of the grain from all the centres for each year have been averaged, and the result is given at the foot of the table. From these average figures, the differences in the character of the grain from year to year is seen to be relatively small.

As the soil and climate conditions in the west of Scotland are in great contrast to those which prevail in the south of England and Wales, figures for the Scotch and English centres have each been averaged and the results put into Table XXII, p. 399.

Table XXII.

|                  | Period<br>of<br>growth<br>days | Kernel                     |                             |                          |          | Dry kernel<br>percentage |      |      | Weight<br>per<br>bushel<br>of grain<br>lbs. | Yield<br>per acre<br>lbs. | Ratio of<br>grain to<br>straw<br>per centage |  |
|------------------|--------------------------------|----------------------------|-----------------------------|--------------------------|----------|--------------------------|------|------|---------------------------------------------|---------------------------|----------------------------------------------|--|
|                  |                                | Weight<br>of 1000<br>grms. | Per-<br>centage<br>in grain | Water<br>per-<br>centage | nitrogen | oil                      | ash  |      |                                             |                           |                                              |  |
| West of Scotland | 144                            | 26.12                      | 75.23                       | 14.36                    | 2.54     | 7.95                     | 2.04 | 43.1 | 2120                                        | 2832                      | 35.6                                         |  |
| England & Wales  | 126                            | 21.78                      | 72.28                       | 12.22                    | 3.07     | 7.39                     | 2.09 | 37.7 | 2375                                        | 3655                      | 41.6                                         |  |
| Seed corn        | ...                            | —                          | 27.04                       | 75.45                    | 12.32    | 2.34                     | 7.46 | 2.16 | 41.5                                        |                           |                                              |  |

The effect on the characters of the grain of one year's growth at the English and Welsh centres compared with that of the "seed corn" are summarised as follows. The "seed corn" was grown in Scotland.

The average weight of the individual grain has diminished by about 23 %, there is a thicker husk, the nitrogen content has increased by about 28 % whilst the oil is lower.

A comparison of the average Scotch with the average English and Welsh centres given in the same table shows a greater variation still for most of the constituents. The variation for the Scotch, English and Welsh centres inclusive for the same year (1911) is shown in Table XXI. p. 398.

The period of growth amounted on an average to 144 days in the south and south-west of Scotland and to 127 days in the south of England and Wales. The average nitrogen content of the dry matter of the straw was 0.31 % in the former and 0.44 % in the latter.

#### PERIOD OF GROWTH AND ITS EFFECT UPON THE GRAIN.

The length of the growing period is a factor which is mainly determined by the climatic and soil conditions, and as it provides data which allows of a more definite interpretation, a table has been drawn up in which the length of the growing period has been taken as the basis for comparison. The figures have been arranged in ascending order of the length of the growing period, see Table XXIII. All the centres are included.

Table XXIII.

| Length<br>of<br>growing<br>period,<br>days | Height<br>above<br>sea-<br>level<br>feet | Kernel                     |                            |                          | Dry kernel,<br>percentage |      |      | Weight<br>per<br>bushel<br>of grain<br>lbs. | Yield per<br>acre, lbs. |       | Ratio of<br>grain to<br>straw<br>percentage | Number<br>of experi-<br>ments<br>(centres) |
|--------------------------------------------|------------------------------------------|----------------------------|----------------------------|--------------------------|---------------------------|------|------|---------------------------------------------|-------------------------|-------|---------------------------------------------|--------------------------------------------|
|                                            |                                          | Weight<br>of 1000<br>grms. | Per<br>centage<br>in grain | Water<br>per-<br>centage | nitro-<br>gen             | oil  | ash  |                                             | grain                   | straw |                                             |                                            |
| 167                                        | 719                                      | 24.68                      | 74.82                      | 11.65                    | 2.36                      | 8.67 | 1.99 | 38.8                                        | 2013                    | 4633  | 30.6                                        | 15                                         |
| 151                                        | 286                                      | 26.12                      | 75.39                      | 13.03                    | 2.32                      | 8.14 | 2.12 | 42.1                                        | 2388                    | 4390  | 35.2                                        | 15                                         |
| 129                                        | 274                                      | 23.88                      | 74.08                      | 12.83                    | 2.89                      | 7.64 | 2.02 | 37.0                                        | 2089                    | 3656  | 36.3                                        | 5                                          |

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The average figure of 167 days, representing a long growing period, contained all the centres, irrespective of the type of soil, situated at high elevations, including those up to and sometimes considerably over 1000 ft. No rainfall figures were recorded, but Watt<sup>1</sup> shows that the rainfall increases with the elevation, while the mean temperature and the hours of bright sunshine decrease. The minimum rainfall would be about 60 inches per annum. Under such conditions the crop is in many cases harvested in an immature state.

The average figure of 129 days represents a short growing period, and includes four of the English centres and one of the Scotch centres. The conditions in this case in so far as the climate is concerned, represent the opposite extreme and there is a tendency of the crop to premature ripening.

The effect upon the grain of the two sets of conditions may be summarised as follows: with a relatively high rainfall and low temperature, growth is so protracted that the crop does not in many cases come to complete maturity, the grain produced is thinner, possesses a thick husk, and is below the average weight. It is rich in oil and the nitrogen is above the average. The weight per bushel, and the yield of grain in proportion to straw is low.

In a warm dry climate where the crop ripens early and often prematurely, the effect upon the size, shape, and thickness of the husk in the grain, is in the same direction, but more pronounced. The oil content is low while the nitrogen is exceptionally high. The bushel weight is also low but the yield of grain to total crop is high. The straw is rich in nitrogen.

In Ontario<sup>2</sup> the average growing period is from 100-108 days, the average percentage of kernel is 71.9, the weight per bushel 33.4 lbs. and the ratio of grain to grain and straw 35.0 %. See also Imported Oats, p. 404.

On an average, in the west of Scotland, a cultural condition which gives rise to a period of growth round about 140 days produces the heavier grain, rich in oil, and a greater yield per acre. Hendrick<sup>3</sup> found that the percentage of oil was higher and the albuminoids lower in the dull cool seasons than in the dry seasons.

<sup>1</sup> Watt, Andrew, "Mean annual rainfall in Scotland, 1871-1910," *Journ. Scottish Meteorological Soc.*, 1910.

<sup>2</sup> Ontario Agricultural College, "Experiments on Oats," 39th Annual Report, 1913, p. 144. Ohio Agricultural Exp. Station, "Experiments with Oat," *Bulletin* 138, March, 1903; 257, Feb. 1913.

<sup>3</sup> Hendrick, J. and Greig, R. B., "Report on Oat Trials," *Bulletin* No. 6, Aberdeen and North of Scotland Agricultural College, 1904.

## SOIL AND ITS EFFECT UPON THE CROP.

A record was kept of the type of soil, as judged by observation, and from information supplied by the experimenters, but beyond this it was not possible to go in the present case. In these experiments it is practically impossible to distinguish between the influence which the soil, apart from that of the climate, exerts on the crop.

At high elevations where there is a considerable rainfall, drainage is the factor of paramount importance. At these elevations the soils are more often in a low state of fertility and there is a lack of available nitrogen due to the unfavourable conditions for nitrification, a result which is reflected in the composition and yield of nitrogen per acre by the crop.

## SUSCEPTIBILITY OF VARIETIES TO CHANGE.

The yield and composition of the grain of individual varieties grown at the various centres, have been tabulated separately. For the present purpose only four varieties, namely, Potato, Sandy, Wide Awake and Beseler's Prolific need be considered. The percentage variation in the size and other characters of the grain have been worked out on the same basis as before and they are given in Table XXIV, p. 402.

The data supplied by these experiments and condensed in Table XXIV is not however considered to be sufficient to provide a definite basis for comparison of the relative degree of susceptibility of varieties to change, under the varying conditions of growth in the west of Scotland. Wright<sup>1</sup> points out that the variation in the yield of grain and straw for the acclimatised straw producing varieties is less than it is for the new or imported grain producing varieties. The same remark applies to the chemical and physical characters of the grain in the present experiment. It also seems clear from these results that the old Scotch varieties such as Potato and Sandy when grown from Scotch seed corn, under the warmer and drier conditions which commonly prevail in the south of England, are more susceptible to change than are the newer varieties.

It is noticeable in the years 1909 and 1910, that the variation in the size of the grain of Potato oat is about 23 % compared with 46 % in the case of Sandy, in other respects the degree of variation is similar. The proportion of singles in the ear of the former is about 63 % and in the latter about 80 %, a fact which may contribute towards the above difference. See Table VI, p. 378.

<sup>1</sup> Wright, R. P., "Report in Oat Experiments," West of Scotland Agri. College Ninth Annual Report.

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Table XXIV.

| Variety             |        | Kernel                     |                        | Dry kernel    |          |          |            |
|---------------------|--------|----------------------------|------------------------|---------------|----------|----------|------------|
|                     |        | Weight<br>of 1000<br>grams | Percentage<br>in grain | Nitrogen<br>% | Oil<br>% | Ash<br>% | Water<br>% |
|                     |        |                            |                        |               |          |          |            |
| Potato,             | 1909   | 20.3                       | 2.7                    | 26.4          | 21.9     | 27.2     | 29.0       |
| "                   | 1910   | 26.1                       | 6.7                    | 43.5          | 28.7     | 13.9     | 43.2       |
| "                   | 1911   | 48.3                       | 8.4                    | 44.8          | 19.1     | 28.9     | 29.0       |
| Average             | ... .. | 31.5                       | 5.9                    | 38.2          | 23.2     | 23.3     | 33.7       |
| Sandy,              | 1909   | 46.4                       | 2.7                    | 29.6          | 23.2     | 26.8     | 28.4       |
| "                   | 1910   | 46.7                       | 5.1                    | 44.9          | 24.9     | 14.1     | 49.0       |
| "                   | 1911   | 48.9                       | 7.1                    | 71.3          | 24.7     | 23.1     | 27.1       |
| Average             | ... .. | 47.3                       | 4.9                    | 48.6          | 24.2     | 21.3     | 34.8       |
| Wide Awake,         | 1909   | 23.2                       | 3.3                    | 35.0          | 23.6     | 35.2     | 28.5       |
| "                   | 1910   | 26.4                       | 12.3                   | 83.7          | 30.1     | 23.7     | 44.3       |
| "                   | 1911   | 33.5                       | 2.3                    | 54.1          | 18.8     | 24.8     | 32.0       |
| Average             | ... .. | 27.7                       | 5.9                    | 57.6          | 24.1     | 27.9     | 34.9       |
| Beseler's Prolific, | 1909   | 23.7                       | 4.6                    | 63.5          | 20.7     | 43.7     | 25.0       |
| "                   | 1910   | 34.5                       | 7.8                    | 55.5          | 32.8     | 27.0     | 43.5       |
| "                   | 1911   | 36.1                       | 14.8                   | 59.6          | 24.8     | 22.8     | 28.1       |
| Average             | ... .. | 31.4                       | 9.1                    | 59.5          | 26.1     | 31.1     | 32.2       |

## CHARACTERS OF THE GRAIN SUBJECT TO VARIATION.

From what has been said in the foregoing pages, the weight of individual grains and the nitrogen content are the most variable characters. The oil, water, and ash, show a less but yet a considerable variation. The proportion of husk varies in the opposite direction to that of the size of the grain.

The impression which remains after the examination of many samples of grain is the comparative ease with which some of the so-called distinctive characters by which the grain of different seedsmen's varieties are recognised, undergo change when the crop is grown under new sets of conditions. The progeny is in many cases hardly recognisable with that of the parent seed. The characters visibly affected are the colour, size of the grain and thickness of the husk. These features appear to remain constant only when the crop is grown under a set of conditions similar or identical to that in which the seed corn was produced.

According to Wilson<sup>1</sup>, colour is a dominant Mendelian character of oat grain. Low<sup>2</sup> and others<sup>3</sup> state that the tendency to the development

<sup>1</sup> Wilson, John H., "Hybridisation of Cereals," *Report of B.A. Meeting, Cambridge* 1904, p. 796.

<sup>2</sup> Low, Daniel, *Elements of Practical Agriculture*, 1834, p. 248.

<sup>3</sup> Chambers' *Encyclopædia*, Article on Oats, 12.

of awns is lessened by cultivation and when present they sometimes wholly disappear.

That the oat crop is subject to greater variation than other cereals<sup>1</sup> is not surprising considering its great powers of adaptability. Wilson<sup>2</sup> says oats are grown as a crop in Sweden as far as 63° Latitude 30 degrees, and in Norway as far as latitude 65. In Russia the polar limit corresponds with that of rye about 62° L. 32 degrees. Turning southwards the climate becomes less and less suitable for oats. This is well seen within the limits of our own country. South of the parallel of Paris 43° L. 50 d. oats are rarely seen in cultivation. In Spain and Portugal they are hardly grown at all, yet they are cultivated successfully in Bengal in latitude 25. Here probably the moisture of the soil compensates for the extreme temperature of the climate. The writings of De Candolle<sup>3</sup> and more recent authors draw attention to the unusual powers of acclimatisation possessed by the oat.

The property of acclimatisation possessed in such a marked degree by the oat seems sometimes to be undervalued. For example in a paper by Russell<sup>4</sup> on the comparative estimate of the human food produced per acre by the different crops in the United Kingdom, no stress is laid upon the fact that oats can be cultivated on land where the cultivation of wheat would be a comparative failure whilst oats can be cultivated wherever wheat is grown.

Deficient warmth and a good rainfall according to crop statistics drawn up by Shaw and Watt<sup>5</sup> are the conditions under which the oat thrives best. These are conditions typical of a great part of Scotland.

#### MINERAL CONSTITUENTS OF THE GRAIN.

The phosphoric acid, potash, lime and magnesia were determined in a number of samples of grain. The average percentage composition of the ash was found to be

|                          |     |     |      |
|--------------------------|-----|-----|------|
| Phosphoric acid $P_2O_5$ | ... | ... | 52.6 |
| Potash $K_2O$            | ... | ... | 21.8 |
| Lime $CaO$               | ... | ... | 5.8  |
| Magnesia $MgO$           | ... | ... | 11.7 |

<sup>1</sup> *Standard Encyclopedia on Agriculture*, Article on Oats.

<sup>2</sup> *Our Field Crops*, by John Wilson, 1859, 1, p. 135.

<sup>3</sup> De Candolle, A., *Origin of Cultivated Plants*, 1884, pp. 373-376.

<sup>4</sup> Russell, E. J., "Comparative values of second-rate arable and pasture land," *Journ. Farmers' Club*, 1917, 5th Nov.

<sup>5</sup> Watt, Andrew, "On Correlation of weather and crops in East of Scotland," p. 181; "On Seasons and Crops in East of England," by W. M. Shaw, p. 179, *Journ. Scottish Meteorological Soc.*, 16, Third Series, No. 30.



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Small differences only were found in the amounts of the mineral constituents present in the different samples of grain.

##### PROPORTION OF WHOLE GRAIN IN OAT SAMPLES.

On an average the amount of chaff, weed seeds and free kernels (shelled grain) in the samples of dressed grain is small, though in individual cases it sometimes amounts to over 15 %, the greater part of which consists of free kernels. It is noticeable that the proportion of "shelled" grain in some farms is high, a fact which may be accounted for by a more drastic dressing of the grain. However when this high figure occurred it did not appear to affect the proportion of kernel in the grain. In a recent paper Stapledon and Loveday<sup>1</sup> found that the highest proportion of "shelled" grain in oat samples was 5.7 % by weight.

The figures are given in the following table along with those for the proportion of light corn.

Table XXV.

|                                                              | 1909    |         |        | 1910    |         |        | 1911    |         |        |
|--------------------------------------------------------------|---------|---------|--------|---------|---------|--------|---------|---------|--------|
|                                                              | Average | Highest | Lowest | Average | Highest | Lowest | Average | Highest | Lowest |
| Free kernels ("shelled" grain), chaff, and weed seeds ... .. | 2.28    | 7.74    | 0.47   | 4.25    | 16.78   | 0.47   | 3.36    | 11.80   | 0.53   |
| Free kernels ("shelled" grain) ... ..                        | 1.64    | 4.68    | 0.12   | 3.56    | 13.89   | 0.11   | 2.47    | 10.80   | 0.24   |
| Percentage "light corn" in total yield of grain ...          | 7.7     | 17.55   | 2.27   | 9.8     | 20.29   | 1.54   | —       | —       | —      |

##### IMPORTED OATS.

Samples of grain imported from Canada, Argentine, Danubian Provinces and Germany were obtained for analysis from cargoes arriving in Glasgow during a period of two years. For these samples the writer is indebted to Thomas Borthwick, Esq., and to Messrs Gilchrist and Thomas of Glasgow. About 96 % of the Manitoban grain imported into this country in 1915 consisted of the varieties Abundance, and Wide Awake, oats. Samples of these two varieties grown in Manitoba were obtained direct from Prof. S. A. Bedford, Superintendent of Demonstration Farms for Manitoba, through the intermediary of the Secretary of the Board of Trade and Commerce for Canada. Their analysis along with the other results are included in the table on p. 405.

<sup>1</sup> Stapledon, R. G. and Loveday, H., "'Shelled' grain in Oats," *Journ. Bd. Ag.*, 1919, 26, No. 5, p. 489.

Table XXVI.

| Variety               | Weight of 1000 kernels "air dry," grs. | Per. centage of kernel in grain analyses | Percentage composition of kernel "dry" |       |                  |         |       | Weight of 1000 grains "air dry," grs. | Weight per bushel grain lbs. | Free kernel (shelled grain) in sample % | Weed seeds, chaff, etc. in sample % | Total whole grain in sample % |
|-----------------------|----------------------------------------|------------------------------------------|----------------------------------------|-------|------------------|---------|-------|---------------------------------------|------------------------------|-----------------------------------------|-------------------------------------|-------------------------------|
|                       |                                        |                                          | Protein %                              | Oil % | Carbo- hydrate % | Fibre % | Ash % |                                       |                              |                                         |                                     |                               |
| Plate Oak No. 1, 1911 | 14.88                                  | 66.53                                    | 11.00                                  | 18.13 | 8.84             | 69.05   | 2.05  | 1.93                                  | 36-38                        | 4.48                                    | 3.89                                | 91.63                         |
| " " 2, "              | 16.86                                  | 60.56                                    | 12.07                                  | 15.06 | 9.27             | 71.70   | 1.98  | 1.99                                  | "                            | 2.36                                    | 4.92                                | 92.72                         |
| " " 3, 1912           | 18.36                                  | 68.02                                    | 11.97                                  | 15.06 | 9.39             | 71.60   | 1.82  | 2.13                                  | "                            | 3.64                                    | 3.89                                | 92.47                         |
| " " 4, "              | 18.64                                  | 67.82                                    | 11.93                                  | 15.18 | 9.36             | 71.44   | 1.90  | 2.12                                  | "                            | 4.36                                    | 4.30                                | 91.34                         |
| " " 5, "              | 19.56                                  | 70.04                                    | 11.94                                  | 13.69 | 8.45             | 72.12   | 1.67  | 2.07                                  | "                            | 3.08                                    | 3.04                                | 91.88                         |
| " " 6, "              | 18.30                                  | 69.97                                    | 10.85                                  | 17.74 | 8.84             | 69.77   | 1.40  | 2.05                                  | "                            | 2.48                                    | 6.88                                | 90.66                         |
| " " "                 | 17.77                                  | 68.17                                    | 11.61                                  | 16.14 | 9.62             | 70.95   | 1.84  | 2.05                                  | "                            | 3.73                                    | 4.48                                | 91.80                         |
| Manitoba No. 1, 1912  | 20.04                                  | 71.59                                    | 12.28                                  | 15.50 | 8.27             | 72.62   | 1.73  | 1.88                                  | 43-46                        | 2.60                                    | 2.56                                | 94.84                         |
| " " 2, "              | 21.26                                  | 72.99                                    | 12.65                                  | 15.17 | 8.27             | 72.92   | 1.81  | 1.83                                  | "                            | 4.24                                    | 3.76                                | 92.00                         |
| " " 3, "              | 22.76                                  | 73.70                                    | 12.52                                  | 16.07 | 8.60             | 72.40   | 1.70  | 1.83                                  | "                            | 3.52                                    | 3.64                                | 90.84                         |
| Canada 1915 crop      | 21.35                                  | 72.76                                    | 12.48                                  | 15.58 | 8.18             | 72.61   | 1.75  | 1.85                                  | "                            | 3.45                                    | 3.99                                | 92.56                         |
| Bonner                | 22.92                                  | 73.05                                    | 11.90                                  | 16.03 | 6.05             | 72.57   | 1.73  | 1.82                                  | 40                           | 2.48                                    | —                                   | 97.52                         |
| " "                   | 20.80                                  | 69.85                                    | 11.83                                  | 17.85 | 6.80             | 71.71   | 2.00  | 1.64                                  | 37                           | 1.94                                    | —                                   | 98.36                         |
| " "                   | 24.98                                  | 73.14                                    | 12.72                                  | 13.38 | 7.57             | 73.05   | 1.94  | 2.16                                  | 38                           | 2.06                                    | —                                   | 97.91                         |
| Pomeranian, 1912      | 15.26                                  | 70.50                                    | 12.25                                  | 10.73 | 8.80             | 70.89   | 1.43  | 2.04                                  | 43-44                        | 0.80                                    | 2.56                                | —                             |
| Danubian No. 1, 1912  | 16.76                                  | 73.18                                    | 11.93                                  | 17.94 | 8.69             | 69.58   | 1.86  | 2.02                                  | 35-37                        | 0.16                                    | 1.84                                | 98.00                         |
| " " 2, "              | 16.72                                  | 72.33                                    | 12.01                                  | 17.07 | 8.41             | 70.11   | 1.83  | 1.98                                  | "                            | 0.26                                    | 4.92                                | 94.72                         |
| " " 3, "              | 16.24                                  | 72.00                                    | 12.07                                  | 17.15 | 8.60             | 70.16   | 1.77  | 2.02                                  | "                            | 0.12                                    | 3.44                                | 96.34                         |
| " " "                 | "                                      | "                                        | "                                      | "     | "                | "       | "     | "                                     | "                            | 0.21                                    | 3.49                                | 96.39                         |

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According to the figures given in the above table, the main points of difference between imported and home grown oats may be summarised as follows: Imported grain is drier, smaller and contains a thick husk. The nitrogen is exceptionally high while the oil is about the same as that found in average home grown grain. The kernel contains more fibre.

Manitoban oats are larger and heavier per bushel than either the Plate or the Danubian oats. This is probably accounted for by the fact that the Manitoban oats are grown in a cooler and moister climate, with a growing period varying from 100-110 days, compared for example with the conditions of growth in the Argentine.

Imported oats are not as a rule dressed beyond the winnowing and screening in connection with the threshing. The weed seeds present provide a means of identification of the country of origin<sup>1</sup>.

### OAT STRAW.

Oats are usually cut before the straw has taken on a uniform yellow colour. If allowed to become dead ripe the loss by the shedding of grain increases. The value of the straw for feeding purposes also diminishes. It is a well-known fact that as the straw matures, the proportion of protein nitrogen increases whilst the digestibility of the crude fibre decreases.

Some figures, obtained in the present investigation, bearing upon this point are given in the following table. See also Figs. 3 and 4, pp. 372, 375, and Table XXVIII in Appendix for the composition of the straw at different stages of growth.

Table XXVII.

|               |     | June  |       | July  |       | August |       |
|---------------|-----|-------|-------|-------|-------|--------|-------|
|               |     | 7th   | 21st  | 5th   | 19th  | 3rd    | 16th  |
| Protein crude | ... | 16.5  | 10.59 | 7.00  | 4.73  | 2.84   | 1.44  |
| " true        | ... | 13.3  | 8.57  | 5.86  | 4.00  | 2.43   | 1.31  |
| " digestible  | ... | 12.1  | 7.52  | 5.16  | 3.11  | 1.99   | 0.87  |
| Fibre crude   | ... | 14.13 | 21.6  | 24.67 | 24.68 | 24.63  | 28.27 |
| Cellulose     | ... | 12.44 | 19.03 | 20.77 | 21.10 | 21.38  | 23.57 |

Aitken<sup>2</sup> states that the straw of grain producing varieties is poorer in nitrogen than that of the straw producing varieties. From what

<sup>1</sup> Stapledon, R. G., "Identification of the country of origin of Commercial Oats," *Journ. Bd. Ag.*, 1916, **23**, No. 2.

<sup>2</sup> Aitken, Dr A. P., "Analyses of Oat Straw and Oats," *Trans. H. and Ag. Soc. of Scotland*, **13**, 1901, p. 284.

has been pointed out in an early part of this paper, the migration of nitrogen from the straw into the kernel begins at the stage when its absorption from the soil appears to cease. It would also seem to follow as a matter of course, that the withdrawal of nitrogen from the straw, would be on a larger scale in the case of the grain, compared with that of the straw producing varieties, and the degree of exhaustion of the nitrogen in the straw in the former case would be greater, unless the plant adjusts its requirements by taking in larger supplies from the soil or produces a kernel poorer in nitrogen. The evidence in favour of the last named is very contradictory, see Table VIII, pp. 382-385.

Unfortunately the bulk of the straw samples which had accumulated were removed during the war, from the building in which they were stored, and were lost, and as yet it has not been possible to replace them. If account is taken of the proportion by weight of grain to straw, the composition of the straw, and of the corresponding grain, it is found that the results obtained in the present experiments are so contradictory and are not sufficiently numerous to bring out the connection which Aitken found. The following table gives the percentage of nitrogen in dry straw and grain respectively.

|                    |     |     | Straw |       |       | Grain |
|--------------------|-----|-----|-------|-------|-------|-------|
|                    |     |     | 1911  | 1916  | 1918  | 1918  |
| Potato             | ... | ... | 0.46  | 0.274 | 0.393 | 2.12  |
| Sandy              | ... | ... | 0.42  | 0.250 | 0.408 | 2.30  |
| Beseler's Prolific | ... | ... | 0.45  | 0.308 | 0.392 | 1.95  |

The composition of the straw should be considered along with that of the yield per acre. In an experiment which was started with the object of finding the degree of variability of the nitrogen content of individual straws and from which the following figures have been taken, it is seen that although the percentage of nitrogen in the straw might be low the actual yield of nitrogen per acre may be greater in the case of straw with a low compared with that of a high nitrogen content.

| Length of straw<br>inches | Weight of straw<br>dry matter<br>grms. | Total weight of<br>nitrogen<br>grms. | Nitrogen<br>% |
|---------------------------|----------------------------------------|--------------------------------------|---------------|
| 27.4                      | .320                                   | .0020                                | .63           |
| 32.4                      | .578                                   | .0023                                | .40           |
| 36.6                      | .828                                   | .0026                                | .31           |
| 42.6                      | 1.415                                  | .0034                                | .24           |

The losses in nutritive material and damage to the crop during bad weather at harvest time, is a serious matter in some years. In Russia<sup>1</sup>

<sup>1</sup> Loudon's *Encyclopaedia*, "Kiln drying of Crops," p. 828.

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and Sweden kiln drying of the crop after cutting, has been resorted to, in order to avoid losses due to weather conditions. The larger use of drying-sheds in wet districts in this country is strongly urged.

#### SUMMARY.

1. In the comparatively humid climate, of the west of Scotland, the water content of oat grain, threshed soon after harvest, amounting, as a rule to between 16 and 18 %, fell, during storage, to between 12·0 and 14·5 %. Grain grown in the drier climate of the south of England and Wales contained on an average 12·2 % compared with 14·4 %. The weight of stored grain varied to a certain extent according to the hygrometric condition of the atmosphere. The maximum variation amounted to between 4 and 5 % of the initial weight of the grain.

In addition to the usual analytical data, it was found to be of great advantage, in connection with each sample of grain examined to keep a record of, date of threshing and date of analysis, proportion of whole grain, weed seeds, husk, etc., average weight of 1000 grains, height above sea-level, type of soil, length of growing period, rainfall, previous cropping and manuring, condition of the crop.

2. Between 11 and 12 % of the fatty substances in the oat kernel is present in the germ (embryo), the remainder is principally in the aleurone layer. The amount of extractable substances varied according to the solvent employed, ether and petroleum ether yielded the smallest and alcohol the largest extract. From 88 to 96 % of the total, was dissolved out by different solvents, in a five hour extraction. With repeated five hour extractions, ether still gave a small residue in the sixth extract. All the extracts contained finely divided solid matter in suspension, which could be made to separate out as a yellow residue and it amounted to between 0·25 and 6 % of the ether extract.

The extracts were found to be slightly higher from "air dry" meal and ordinary ether compared with "dry" meal and dry ether.

Free fatty acids were almost absent in the oil from freshly ground kernel, but afterwards they rapidly increased and in 24 days, calculated as oleic acid, they formed over 55 % of the extract. Drying the grain such as is done in the manufacture of oatmeal, had the effect of slowing down the rate of hydrolysis of the fat, but the amount of acid finally liberated was the same.

Sources of error in the usual methods for the determination of water and fibre were pointed out.

3. In the growing oat under the soil and climatic conditions which prevail at Kilmarnock, the absorption of nitrogen and potassium compounds from the soil practically ceased at the stage when the kernel began to develop, whilst the absorption of phosphorus, total ash, and the accumulation of dry matter, continued until the plant was mature.

Phosphoric acid and potash formed 50 % of the total weight of ash absorbed by plants of about two months growth, and which fell to about 26 % in the ripe plant.

• Migration of nitrogen, potassium and phosphorus compounds from the straw, husk and chaff into the kernel proceeded until maturity was reached.

The available supplies of mineral and nitrogen compounds in the soil at the successive stages of growth in the life of the crop were not determined, so that the influence of these supplies upon the absorption of these compounds was not shown.

No evidence was obtained, except in the case of potassium at one of the cuttings, to show that plant constituents pass out of the plant into the soil again during the growing period, unless the stage at which their absorption appears to cease, is interpreted as being due to the rate of ingress being equal to that of egress.

The composition of the kernel, straw, chaff, husk at the successive stages of the growing period was determined.

4. Component grains in a spikelet varied in weight, proportion of husk, and in chemical composition. As a rule the "firsts" of the "doubles" and the "firsts" and "seconds" of the "trebles" were large grains, the "seconds" of the "doubles" and the "thirds" of the "trebles" were small grains, the remainder were medium sized. The larger grains on an average were richer in oil and in nitrogen.

The number of grains in a spikelet varied also according to the variety and to the cultural conditions. Accordingly it follows that the uniformity in the size and in the composition of individual grains comprising a sample is subject to considerable variation.

5. The composition of the kernel and of the grain of a large number of varieties of oat was determined.

Colour, weight of kernel, and proportion of kernel in the grain, formed the basis upon which the analyses were tabulated.

White, yellow, black and grey coloured grains formed the principal groups. These were again separated into sub-groups according to the proportion of husk and the average size of individual grains.

A small kernel was taken as having an average weight up to 21 grams.

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a medium, from 22 to 25 grams, a large, from 26 grams and over, per 1000 kernels. A thin husk included grain containing a proportion of 75 % and upwards of kernel in the grain, a medium, 73 to 74 % and a thick, up to 72 % of the average weight of kernel in the grain. Subdivisions into, old and new; grain and straw; early and late varieties; also into open and one-sided inflorescence; and winter oats, were made.

By arranging the analyses of the members of a group according to the weight of the kernel, a connection was shown to exist between this and other characters of the grain. For example in the case of the white, grains with a thin husk, it was shown that as the kernel increases in weight, the proportion of husk decreased, the oil and fibre diminished, while the carbohydrates, the yield per acre of grain and the proportion of grain to grain and straw increased.

The grain of New Varieties are usually medium or large and contain thick more often than thin husks.

A summary of the classification is given in Table X, p. 387.

The kernel of Native oats was exceptionally rich in oil and nitrogen. It is a small kernel with an unusually thin husk, although the proportion of kernel in the grain is low.

Oatmeal with a low oil and relatively high nitrogen content when fed to young pigs, produced a slightly higher daily increase in live weight for the first three weeks of feeding, compared with the increase produced from oatmeal with a high oil and average nitrogen. From the fourth to the thirteenth week, the increase was in favour of the latter.

The "mealing power" of oats, calculated from the "kiln dried" grain varied in proportion to the amount of kernel in the grain. Calculated from the "air dry" grain the yield of oatmeal was further modified according to the water content of the grain.

The average water content of oatmeal at the time of milling was 1.8 % at the end of 50 days in the months of June and July, it increased to 6.5 %.

The proportion of water soluble (1) nitrogen compounds, (2) ash constituents, in a good sample of Scotch oatmeal, varied greatly from that obtained in an inferior sample, made from Plate oats.

The proportion of germ (embryo) in the grain of four varieties varied from 2.6 to 4.8 %. It was rich in oil and nitrogen.

The nitrogen in the chaff varied from 0.48 to 0.95 % and in the husk from 0.15 to 0.50 %, in the varieties examined.

6. A connection similar to that which was found to exist between

the size and other characters of the grain, in the case of varieties, was also found to exist, when cultural conditions was the cause affecting the size of the grain. There was however a difference in the latter case, in that the oil content remained stationary whilst the nitrogen diminished as the size of the kernel increased. The water content and the weight per bushel of the grain increased as the size of the kernel increased.

The close connection which appears to exist between the effect of variety and that of cultural conditions on the size and composition of the grain is interesting, inasmuch as it is an indication that many of the strains of oats have come into existence by a process of selection based upon the size of the grain.

Perhaps the point of practical importance is the fact that the yield per acre is associated directly with the average size of individual grains. The larger grain gives the greater yield, weight per bushel, and proportion of kernel. The production of straw varies in the opposite direction to that of the yield of grain.

Notwithstanding the lower nitrogen content, the yield per acre of nitrogen for the heavier grain is greater, so also is the total yield of food units, although the larger grain contains slightly more water.

7. The influence of varying cultural conditions upon oat characters, as shown in the present experiments are summarised as follows:

Season, covering a period of nine years, produced comparatively little change in the composition of the grain. It was less than that produced by growing the crop on land, which had been under permanent pasture for a number of years and newly ploughed up, compared with the crop grown on land under ordinary arable cultivation in the previous year. In none of the characters of the grain did the maximum change reach more than about 11% during the nine years.

Moderate dressings of nitrogen, or phosphatic or potassic manures, applied either alone or mixed, to land in an average state of fertility, produced even less effect than season upon the size and composition of the grain.

Grain grown from seed sown in the month of January, on an average, was a little heavier and contained less husk than the grain produced from later sowings. The April sown seed yielded the lightest grain with the thickest husk. Although the ash diminished in the same order as the size of the grain, the other constituents of the grain did not show any marked variation. The results covered two years experiments, but the yields of grain per acre were unreliable, since the early sown corn, being ripe first, suffered more from birds and there were many blank



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spaces. The average weight of individual plants was greater from the early sown seed.

Locality, which embraces elevation, climatic and soil conditions, etc., was the cause of the greatest modification in the characters of the grain. In the course of three years' experiments on farms situated in the west of Scotland, the maximum annual variation amounted to from 18 to 38 % for the average weight of individual grains; 37 to 54 % for nitrogen; 17 to 29 % for oil; 17 to 35 % for ash and 21 to 31 % for water. But if a comparison is made between the average composition of the grain of one year compared with that of another year, the variation is only slight.

Compared with the seed corn, the average grain, grown at several centres in the south of England and Wales from Scotch seed, had a thicker husk, the average weight of individual grains diminished by about 23 %, the nitrogen content was higher by about 28 %, the oil remained unchanged, while the average grain grown in the same year at a number of centres in the west of Scotland varied but slightly from that of the seed corn. The period of growth in the former case averaged 126 days and in the latter 144 days. The nitrogen in the straw was 0.44 % compared with 0.31 %.

When the period of growth was taken as the basis of comparison, it was found that a long period, which averaged 167 days, comprised all the centres at high elevations, irrespective of the type of soil. The grain was below the average weight and had a thick husk. It was rich in oil and the nitrogen was above the average. While a relatively short period of growth, which averaged 129 days, the effect upon the weight of the grain, and thickness of husk was in the same direction but more pronounced. The oil was low and the nitrogen exceptionally high.

In the west of Scotland an average growing period round about 140 days indicates conditions suited best to the growing of oats.

The data in connection with the relative susceptibility of varieties to change did not allow of very definite conclusions to be drawn, except that the old Scotch varieties are less susceptible to change in this climate than the newer varieties. The percentage variation for several varieties is given in Table XXIV, p. 402. Compare also analyses of New Abundance and Banner grown in Canada, p. 405, with that of the same varieties grown in this country, pp. 382 and 383.

8. Grain characters subject to greatest variation are the average weight of individual grains, and the nitrogen content, while the oil, water, ash and the proportion of kernel show a less but yet a considerable variation.

9. The proportion of whole grain, weed seeds, etc. varied considerably in the samples from the different farms. It is suggested that the threshing and dressing of the grain is the main cause of this.

10. Analyses of samples of grain of imported oats arriving in Glasgow over a period of two years were made. Compared with home grown oats the grain is drier, smaller, contains a thick husk, is rich in nitrogen, and oil, and has a low weight per bushel. The kernel contained more fibre.

Of the imported oats, the grain grown in the moister and cooler climate of Manitoba was the larger and heavier per bushel. The growing period varied from 100 to 110 days.

11. Data relating to the composition of the straw was unfortunately incomplete, except in so far as the composition was influenced by the stage of growth.

In conclusion the author wishes to express his thanks to Mr Peter Caldwell who carried out by far the greater part of the analytical work, and to Miss J. Dawson who carried through all the mechanical analyses of the grain.

## APPENDIX.

Table XXVIII.

*This Table shows the percentages of the constituents in the dry matter of the kernel and of the straw at the different stages of growth.*

|                                                                                                                    |     | Kernel |       |       |       |        |       |       |       |
|--------------------------------------------------------------------------------------------------------------------|-----|--------|-------|-------|-------|--------|-------|-------|-------|
|                                                                                                                    |     | July   |       |       |       | August |       |       |       |
|                                                                                                                    |     | 20th   | 24th  | 27th  | 31st  | 3rd    | 7th   | 10th  | 14th  |
| Dry matter                                                                                                         | ... | 25.3   | 33.8  | 38.6  | 43.0  | 52.0   | 55.6  | 60.0  | 64.1  |
| Nitrogen                                                                                                           | ... | 2.09   | 2.41  | 2.46  | 1.91  | 1.89   | 2.03  | 2.43  | 1.99  |
| Alcohol extract*                                                                                                   | ... | 14.2   | 7.98  | 5.95  | 4.89  | 3.24   | 3.23  | 3.24  | 2.77  |
| Ether extract                                                                                                      | ... | 10.22  | 11.89 | 11.55 | 10.22 | 9.75   | 8.90  | 7.84  | 7.03  |
| Ash                                                                                                                | ... | 3.54   | 3.09  | 2.58  | 2.34  | 2.33   | 2.23  | 2.43  | 2.48  |
| Phosphoric acid, $P_2O_5$                                                                                          | ... | 1.49   | 1.34  | 1.21  | 1.10  | 1.08   | 1.07  | 1.08  | 1.11  |
| Potash, $K_2O$                                                                                                     | ... | 1.44   | 1.12  | 0.91  | 0.84  | 0.83   | 0.77  | 0.73  | 0.68  |
| * Includes sugars. The alcohol extraction was made from the sample which had been previously extracted with ether. |     |        |       |       |       |        |       |       |       |
|                                                                                                                    |     | Straw  |       |       |       |        |       |       |       |
| Dry matter                                                                                                         | ... | 21.7   | 27.5  | 27.7  | 28.5  | 27.9   | 28.8  | 30.7  | 31.8  |
| Nitrogen                                                                                                           | ... | 0.515  | 0.542 | 0.426 | 0.370 | 0.317  | 0.293 | 0.250 | 0.260 |
| Ether extract                                                                                                      | ... | 2.58   | 2.80  | 2.70  | 2.51  | 3.10   | 2.97  | 2.74  | 2.60  |
| Crude fibre                                                                                                        | ... | 32.8   | 32.8  | 32.5  | 33.5  | 37.1   | 40.5  | 41.4  | 43.0  |
| Ash                                                                                                                | ... | 5.49   | 5.34  | 6.06  | 6.50  | 6.16   | 6.69  | 6.27  | 6.03  |
| Phosphoric acid, $P_2O_5$                                                                                          | ... | 0.296  | 0.250 | 0.233 | 0.234 | 0.210  | 0.210 | 0.155 | 0.164 |
| Potash, $K_2O$                                                                                                     | ... | 1.03   | 0.88  | 0.81  | 0.86  | 0.95   | 0.87  | 0.94  | 0.98  |

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Table XXIX.

| Month                          | Rainfall<br>inches | Rainy days | Mean<br>temperature °F. | Hours, bright<br>sunshine |
|--------------------------------|--------------------|------------|-------------------------|---------------------------|
| January ...                    | 3.78               | 19         | 38.7                    | 31.2                      |
| February ...                   | 3.39               | 18         | 38.9                    | 50.3                      |
| March ...                      | 3.06               | 18         | 40.7                    | 94.6                      |
| April ...                      | 2.47               | 16         | 44.4                    | 133.2                     |
| May ...                        | 2.50               | 17         | 50.2                    | 163.6                     |
| June ...                       | 2.13               | 13         | 54.8                    | 182.2                     |
| July ...                       | 2.98               | 16         | 57.6                    | 168.4                     |
| August ...                     | 4.07               | 19         | 57.2                    | 135.6                     |
| September ...                  | 2.88               | 15         | 53.3                    | 114.3                     |
| October ...                    | 4.06               | 18         | 47.7                    | 71.2                      |
| November ...                   | 3.82               | 18         | 41.8                    | 42.2                      |
| December ...                   | 4.29               | 21         | 39.6                    | 24.2                      |
| Yearly average,<br>1902-18 ... | 39.43              | 208        | 47.1                    | 1212                      |

Table XXX.

|                                       | Soil<br>% | Subsoil<br>% |
|---------------------------------------|-----------|--------------|
| Mechanical analysis                   |           |              |
| Fine gravel ...                       | 10.7      | 9.8          |
| Coarse sand ...                       | 26.8      | 25.3         |
| Fine sand ...                         | 23.7      | 29.7         |
| Silt ...                              | 20.2      | 15.4         |
| Fine silt ...                         | 6.3       | 13.9         |
| Clay ...                              | 7.3       | 5.9          |
| Chemical analysis                     |           |              |
| Moisture ...                          | 5.0       | 4.6          |
| Loss on ignition ...                  | 13.4      | 10.1         |
| Nitrogen ...                          | 0.38      | 0.24         |
| Carbonate of lime ...                 | 0.22      | 0.10         |
| Phosphoric acid, $P_2O_5$ , total ... | 0.23      | 0.20         |
| "    "    " available ...             | 0.025     | 0.016        |
| Potash, $K_2O$ , total ...            | 0.26      | 0.24         |
| "    available ...                    | 0.011     | 0.009        |

Water level about 40 inches below the surface.

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## MODERN METHODS FOR EXPERIMENTS WITH FERTILISERS AND MANURES

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EVEN an amateur in agricultural science will admit that nowadays the fertilising effect of a substance cannot be tested merely by adding the substance to the soil and inspecting the resulting crop. This is not an experiment, it may give rise to an observation, but not to a conclusion. The production of the crop is connected with the fertilising process as a *post hoc*, not as a *propter hoc*.

A real experiment for the study of a fertiliser problem must, like most other experiments, be comparative. If we wish to know the effect of a fertiliser on a crop, we have to compare the crop produced on an unfertilised plot of soil with the crop from another plot, identical with the first one in all respects except the supply of the fertiliser in question. The recognition that this is an indispensable condition for the rational arrangement of an experiment marks the commencement of scientific research in this branch of agriculture. Therefore the experiments at Rothamsted form the classic model of agricultural experiments. They were the model for the similar experiments at Copenhagen, at Aas in Norway, at Grignon in France and other places on the continent.

The method of field experiments presupposes a complete homogeneity of the whole field, of which the different plots are to be compared. But here indeed arises a difficulty. If we set out several trial plots on a field, and treat them all in the same way, we shall never get agreement in crop yields from them. The difference may be quite surprising, it may rise to more than 100 per cent. But if this is so, it is obvious that the basis of the field experiments is failing. If from a fertilised plot we get more crop than from an unfertilised, we shall never be certain whether the excess is an effect of the fertiliser or if it is due to the original difference of the two plots.

We know that at Rothamsted the soil of the trial fields is fortunately extraordinarily homogeneous, and of course this may happen too in other localities, but we have no guarantee, and in many countries it would be impossible to set out a series of uniform trial plots of agreeing

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uniformity. And even at Rothamsted we see from the account given by Sir A. D. Hall in his book of fertilisers and manures p. 361, that two unmanured grass plots, for which the relative yield on the average of all years from 1856-1905 differed 10 per cent., showed in one year a difference of 196 per cent., in another year a difference of 90 per cent. The probable error of 50 years mean is  $\pm 1.9$  per cent., but series of 50 years experiments are exceptional, and even if we had more, the method is too slow. At Aas in Norway the late agricultural chemist, V. Direks, laid out some trial plots for fertiliser experiments on a field during the years 1869-1880. The two control-plots, which during the whole period remained without any sort of manure, gave on the average relative yields of 100 : 120.

It therefore seemed reasonable when Paul Wagner of Darmstadt about 40 years ago pronounced the field experiments valueless as a scientific method of research. The pot culture method developed by him to a high degree of exactness was for long regarded by many investigators as the best way to ascertain the value of any fertiliser. And although the writer cannot accept the results Wagner himself has published the method will always keep its value for precision. Pot experiments have been used before Wagner, e.g. by Saussure, Boussingault, Sachs, Hellriegel and others, at Rothamsted by Lawes and Gilbert, but more for purely physiological researches than for agricultural purposes. The earlier investigators generally used water or pure sand in their pots, Wagner used natural soil from the field. His purpose was to substitute the heterogeneous field plots by a series of pots, all filled with the same natural soil, so that they were all strictly comparable. Nevertheless there are problems connected with fertilisers, which cannot be solved by pot-experiments, and at all events the results of the pot-experiments have to be confirmed and controlled by field experiments. To improve the method of field experiments it has been proposed to make the plots so small that they can be repeated several times, say four or five, over the field. Wagner himself was urged to adopt field experiments, and he drew up a scheme as the following:

|   |   |   |   |   |   |   |   |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 |
| 4 | 5 | 1 | 2 | 3 | 4 | 5 | 1 |

The duplicate plots here lie far from each other, spread over the field, to allow for the inequalities of the soil: on an average of all the similar

plots, the inequalities should be smoothed out. For special cases the scheme may be simplified. If the question is to try a potassium fertiliser (K), the scheme can be reduced as follows:

|            |            |            |
|------------|------------|------------|
| <i>O</i>   | <i>NP</i>  | <i>NPK</i> |
| <i>NP</i>  | <i>NPK</i> | <i>O</i>   |
| <i>NPK</i> | <i>O</i>   | <i>NP</i>  |

*N* signifies a nitrogenous substance, *P* a phosphatic fertiliser, *O* the quite unmanured plots.

This may be an improvement, but Wagner may be right in claiming that even this will not make field experiments satisfactory for exact scientific researches.

But if some plots give surprising results they must not be excluded from the average.

Lately another German author, Professor Ehrenberg, at Göttingen, an investigator of great originality and honesty, has proposed that every field experiment is to be prepared with a control experiment, in which all the plots should be treated for a whole year exactly uniformly without any sort of manure. Only if the crops from all the plots agree, can the field be accepted as suitable for a further comparative experiment. I think that it will be rather difficult to find many fields which will stand this test, at least in hilly countries.

A wholly different principle for field experiments has been given by the late Professor Bastian Larsen at the Agricultural University at Aas in Norway. The heterogeneity of the soil is regarded as a thing to be recognised and not evaded. The variations of the soil are measured by a great number of control plots adjacent to each of the trial plots, as will be seen in the following scheme:

|          |          |          |          |          |          |          |          |          |
|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| <i>A</i> | <i>O</i> | <i>B</i> | <i>C</i> | <i>O</i> | <i>A</i> | <i>B</i> | <i>O</i> | <i>C</i> |
| <i>O</i> | <i>A</i> | <i>B</i> | <i>O</i> | <i>C</i> | <i>B</i> | <i>O</i> | <i>C</i> | <i>A</i> |
| <i>B</i> | <i>C</i> | <i>O</i> | <i>A</i> | <i>B</i> | <i>O</i> | <i>C</i> | <i>A</i> | <i>O</i> |
| <i>O</i> | <i>A</i> | <i>B</i> | <i>O</i> | <i>C</i> | <i>A</i> | <i>O</i> | <i>B</i> | <i>C</i> |

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There are set out 36 plots on the field. Of these the 12 plots marked with *O* are controls without manure. *A*, *B*, *C* are the trial plots treated with fertilisers in different ways. We suggest here four parallel plots of each treatment, and a series of three different treatments, e.g. *A* = nitrogen only, *B* = nitrogen + phosphate, *C* = nitrogen + phosphate + potassium. But of course we may extend indefinitely both the number of the parallels, and the number of the ways of fertilising. In the centre of the field every one of the manured trial plots is surrounded by three unmanured controls. For each of the trial plots the surplus of its yield over the average yield of the three adjacent controlling plots is calculated.

This method originally developed by Bastian Larsen for the comparison of different varieties of plants, is of course equally applicable to the study of fertilisers. Even if the different parts of the field lack uniformity the disadvantage will be annulled by the great number of controlling plots. Even if the three controlling plots adjacent to a trial plot should give yields so divergent that under other circumstances we should condemn them as useless, we can nevertheless compare their average with the yield of the interjacent trial plot, because the yield of the trial plot, if it had had no manure at all would probably agree with the average of the three adjacent controlling plots. At all events it is evident, that the faults arising from the inevitable heterogeneity of the soil, will by this "differential method" diminish with the number of the controlling plots more than in any other method. Furthermore the repetition of each plot helps to level the differences, and the more we can multiply the series of consecutive plots over the field, the nearer shall we get to a true average. The mean error of the results is obtained from the parallel differential values by the method of least squares. As to the size of the plots in the field experiments there are great divergencies in the opinions of the authors. Sir A. D. Hall proposes a size of  $\frac{1}{20}$  acre = 2 ar., Wagner proposes 1 ar., another German experimenter, Professor Mitscherlich, 0.5 ar. as the best size of the plots. In 1897 Professor B. Larsen compared the yield of grass from a field of 20 ar., which he divided either in a few large or in many small plots. He found the following connection between the size of the plots and the mean error of the yield:

|                 | 1 ar. | $\frac{1}{2}$ ar. | $\frac{1}{3}$ ar. | $\frac{1}{4}$ ar. | $\frac{1}{5}$ ar. |
|-----------------|-------|-------------------|-------------------|-------------------|-------------------|
| Mean error..... | ± 11% | ± 7.43%           | ± 5.07%           | ± 3.42%           | ± 3.05%           |

According to this the greatest degree of accuracy is given by plots of

the size  $\frac{1}{3}-\frac{1}{4}$  ar. each, i.e.  $\frac{1}{12}-\frac{1}{16}$  acre. For practical reasons however plots of  $\frac{1}{3}-\frac{1}{2}$  ar., i.e.  $\frac{1}{12}-\frac{1}{8}$  acre, are generally used in Norwegian field experiments. Larsen's experiment was made on grassland: arable crops might have given a different result for the most convenient size of plots. Probably the result will be influenced by the soil, the climate and other local circumstances.

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## A QUALITATIVE TEST FOR SOUR SOILS.

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SINCE the publication in 1914 of the results obtained by Daikuhara<sup>(2)</sup> in an investigation of certain acid soils of Japan, considerable prominence has been given in the literature of Soil Chemistry to the presence of iron and aluminium salts in the solution of sour soils.

Harris<sup>(1)</sup> had demonstrated the possibility of aluminium being removed from the relatively non-reactive part of soils and kaolins, and then to be held in such a manner that it is practically resistant to water, but is partially and appreciably interchangeable with the cation of a neutral salt. The occurrence of iron and aluminium salts in certain pine forest soils, which have been covered with "raw humus," is described by Kappen<sup>(5, 6)</sup>, and Spurway<sup>(7)</sup> has discussed the different ratios of easily soluble calcium oxide to iron and aluminium oxides which obtain in acid and alkaline drift soils. A similar alteration in the ratio of the oxides of calcium and magnesium to those of iron and aluminium, accompanying an alteration in reaction, has been shown by Howard<sup>(11)</sup> in some soils of the Rhode Island Agricultural Experiment Station.

The value of the analytical data respecting the causal association of iron and aluminium salts with soil acidity is greatly enhanced by the work of Hartwell and Pember<sup>(9, 10)</sup> which demonstrates the similar effects of aluminium sulphate and the extracts of acid soils *on the growth of plants*, and the dissimilar effects of sulphuric acid and either the aluminium salt or the soil extract.

The consistent indication of the above-mentioned work is towards the following general conception. The soil reactions (to discuss the nature of which is no part of the present purpose) make on the reactive part of the soil a demand for bases. This demand is normally met, in most soils with which we are acquainted, by calcium and magnesium compounds; but it is met by less suitable compounds of iron and aluminium when the supply of available calcium and magnesium compounds is temporarily depleted, and when the soil solution, being no longer basic in reaction, can admit iron and aluminium by ionic interchange.

The association of aluminium with the "sourness" of the medium of plant growth seems to find further support in the work of Stoklasa<sup>1</sup>. This investigator has shown that aluminium occurs in relatively large amounts in the Hydrophytes, whose habitat will generally be more sour than that of the Xerophytes which contain only small traces of aluminium. It would appear here, that plants which normally grow in wet places are acclimatized to the effects of aluminium.

If it is generally true that in sour soils the cations in the soil solution replace iron and aluminium from their salts absorbed in the reactive surface of the soil particles, then any sour soil, when treated with a neutral solution of a potassium salt, may be expected, in the exchange of cations, to give up some amount of iron to the solution. If the potassium salt used is the thiocyanate, the fact of iron going into solution can be qualitatively demonstrated forthwith by the appearance of the red colour of ferric thiocyanate.

In quite another connection, the writer recently had occasion to apply a solution of potassium thiocyanate to various soils of known character, and it was incidentally noticed that the red colour appeared only when the solution was applied to acid soils. The solution applied to non-acid soils remained colourless.

In furtherance of this observation six soils which had been found by the Hutchinson-MacLennan method not to absorb calcium bicarbonate were taken at random from the departmental soil stores, together with six others known to have lime requirements which had been determined<sup>1</sup> by the same method to be 0.03, 0.06, 0.07, 0.11, 0.15 and 0.17 per cent.  $\text{CaCO}_3$  respectively. About 2-3 gm. of each of the twelve soils were placed in test-tubes and about 5 c.c. of a bench solution of potassium thiocyanate were added. The solution in contact with each of the soils having a lime requirement was found to be pink or red within an hour, while no trace of pink colour was seen in the other six cases, even after standing for three weeks. In two cases (those with lime requirements of 0.03 and 0.06 per cent.  $\text{CaCO}_3$ ) the pink colour was not apparent at first and, while indubitably present, was not very pronounced after an hour. The test was therefore repeated with these twelve soils using an *alcoholic* solution of potassium thiocyanate, since

<sup>1</sup> Most of the soils referred to in this paper had been sampled by Dr J. A. Hanley by whom the lime requirements had been determined and kindly placed at the writer's disposal. The results are taken here for their qualitative rather than their quantitative value, for there is no intention of implying any particular opinion that may be held by the writer, or by his colleague, of their quantitative meaning.

it was expected, on both physical and chemical grounds, that the concentration of the ferric thiocyanate in the liquid phase would be increased by making this alteration. A great improvement in the delicacy of the test resulted. In five minutes all the soils had settled leaving clear solutions which were emphatically red or pink over the soils deficient in lime and quite colourless over the remainder.

In further confirmation of the test thirty-six soil samples were taken at random from the above-mentioned collection of Yorkshire soils. Twelve showed no lime requirements by the Hutchinson-MacLennan method, and twenty-four showed lime requirements varying from 0.03 to 0.30 per cent.  $\text{CaCO}_3$ . These were tested with an alcoholic solution of potassium thiocyanate containing 40 gm. thiocyanate in a litre of 95 per cent. alcohol. Distinct pink or red colours obtained in those solutions which were in contact with the soils capable of absorbing calcium bicarbonate, while the remainder were quite colourless.

The test has subsequently been applied to various soils brought into the laboratory for examination in respect of lime requirement, and has correctly predicted in every case whether or not the soil would absorb calcium bicarbonate.

Altogether over 70 soils have so far been examined by the thiocyanate test, and without exception those which absorb lime have been identified; indeed, one soil, stated to have a lime requirement of 0.035 per cent.  $\text{CaCO}_3$ , gave no pink colour with the thiocyanate, and this led to the discovery of a clerical error whereby the soil had been wrongly described as having a lime requirement.

Ammonium thiocyanate in equivalent amount is much less sensitive than the potassium salt. This, of course, would be expected from van Bemmelen's observations of the relative rates of exchange of ions between hydrous silicates and solutions. Both the ammonium and potassium salts are much less sensitive in aqueous solution than in alcohol. An alcohol-ether solution of thiocyanate is much more sensitive than an alcoholic solution, but the latter gave a satisfactory indication in the cases examined. An alcohol-ether solution is useful for borderline cases.

It is concluded that if 2-3 gm. of a soil are placed in a test-tube and vigorously shaken with about 5 c.c. of a concentrated alcoholic solution of potassium thiocyanate, the development of a pink or red colour in the solution, which increases on standing, will indicate, qualitatively, a deficiency of lime in the soil. If the colour is very faint it may be more easily seen after filtering. A definite alkalinity of the soil may be

confirmed by adding a few gm. of the soil to an alcoholic solution of thiocyanate which is rendered slightly pink by a trace of ferric thiocyanate. The pink colour will be removed if the soil is alkaline.

The reaction involved in this test is essentially an exchange of ions and not an ordinary dissolution of some soluble iron compound. This was shown by taking some of the soils which gave a colour with aqueous thiocyanate, shaking them with water for five minutes and then filtering the solution into a test-tube containing thiocyanate crystals. No pink or red colour developed.

The colour of the ferric thiocyanate in the solution over the soils deepens visibly for about 48 hours, and the final equilibrium is probably only established after a much longer period (see Leiningen, *Kolloide-Zeitsch.* 1916, **19**, 165). But it is clear that even after equilibrium is finally established, the colour cannot be used as a comparative measure of the lime requirement of different soils; for only iron is identified in this test, in a mixture of iron and aluminium in proportions which will vary from one soil to another. Other reasons also preclude a quantitative interpretation of the colour. On the same soil however the test may afford useful indications of the variation of acidity. Two cases may be quoted in illustration.

The thiocyanate test was applied to soil samples taken from different parts of a field on the Leeds University Farm at Garforth, and one area was found by the test to have no lime requirement. This was afterwards identified with the place of a chalking experiment in 1911.

In another instance a bare patch on one of the University lawns in the city of Leeds was sampled, and separate samples were collected from the soil 0"-3" from the surface, 3"-6" from the surface and 6"-9" from the surface. Treated with alcoholic thiocyanate solution, the soil of the top 3" immediately induced a red colour in the solution, while the samples from greater depths did not. A column of this soil from which the surrounding soil had been dug away, was then divided into half-inch layers, by means of a nickel spatula, to a depth of  $2\frac{1}{2}$ ", and soil from each of the five layers was tested with alcoholic thiocyanate solution. The soil of the top half-inch gave an opaque blood red colour to the solution immediately, the next layer gave a red colour, the third layer a pink colour, and the remainder gave no colour at all. The acidity was thus shown to be intensively confined to the surface layer of soil — a circumstance easily correlated with "smoke damage."

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## THE FLOCCULATION OF SOILS.

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THE flocculation of small soil particles by the action of lime is thoroughly established in practice and very incompletely understood in theory. The many investigations of the phenomenon which are recorded indicate that it is akin to the coagulation of sols by the action of electrolytes; and it can hardly be doubted that the flocculation of clay is, at least partially, a colloidal change<sup>1</sup>.

Hall and Morison<sup>2</sup> made a quantitative investigation of the clearance of kaolin suspensions by electrolytes, but failed to correlate their results with the "Valency Law" which was very prominent in the literature of Colloid Chemistry at that time. In this failure the Rothamsted investigators have been abundantly justified, for the Valency Law, *as a law*, has been placed out of court. The attempt to establish this law, in which the coagulating power of an ion was regarded as a function of its valency, was made in accordance with the concept that coagulation by electrolytes was solely and simply due to the neutralization of a static electric charge on the colloid, by a charge of opposite sign on the precipitating ion. The earlier experimental data published by Hardy<sup>3</sup>, Bodländer<sup>4</sup>, and many others, showed an approximate agreement with the theoretical deductions of Whetham<sup>5</sup>, and appeared to give some support to the proof of a Valency Law; but more recent work has revealed cases in which the relative precipitating power of ions is not even approximately in agreement with the theoretical requirement put forward by Whetham. It appears that the absorption by the colloidal particles of the precipitating ion, is an important factor in determining the precipitating power of that ion<sup>6</sup>; and this absorption is, as far as we know, specific for any given case<sup>7</sup>.

<sup>1</sup> Pickering has advanced a different explanation. See *Proc. Roy. Soc.* 1918, **94** (A), 315.

<sup>2</sup> *Journ. Agric. Sci.* **2**, Part 3, 244.

<sup>3</sup> *Zeitsch. physik. Chem.* 1900, **33**, 355.

<sup>4</sup> *Jahrb. Mineral.* 1893, **3**, 147.

<sup>5</sup> *Phil. Mag.* 1899, **5**, 48, 474.

<sup>6</sup> See Lewis, *A System of Phys. Chem.* 1918, **1**, 316-8.

<sup>7</sup> Bancroft, W. D., *Journ. Phys. Chem.* 1915, **19**, 363.

In any attempt to correlate the flocculation of soil particles with the established facts of Colloid Chemistry, attention must be given to the complications of the soil system. There are two obvious causes of complication, each of which will have an important bearing upon the action of electrolytes on the soil. First, the soil particles are "protected" by organic and inorganic colloids: second, the soil is a system of particles of all sizes. These two facts alone forbid any straightforward comparison of flocculation in the soil with coagulation in a simple suspensoid sol.

It was thought that further evidence on this subject—and therefore on the physical constitution of the soil—might be forthcoming from an investigation of the effect of alkalinity on flocculation, for some colloids, silicic acid for example, behave differently from most suspensions when flocculated in alkaline solution. The following experiments were therefore carried out in order to examine the flocculation, by calcium salts, of neutral and alkaline suspensions of clay, silt and soils.

#### *Experimental.*

The following soils and subsoil were used in these experiments:

- (1) *A Clay Soil*. A drift soil containing 30 per cent. clay.
- (2) *Peat Mires*. A silt soil from the Leeds University Farm at Garforth, containing a large amount of organic matter.
- (3) *Field 113*. A typical silt soil from the University Farm containing 7 per cent. coarse silt, 14 per cent. fine silt and 4 per cent. clay.
- (4) *A Palaeozoic Silt Loam*<sup>1</sup> from Esgair Heulog, Eglwysbach, Denbighshire.
- (5) *An Anglesey Medium Loam*<sup>1</sup> from Cefndu Mawr, Gaerwen.
- (6) *Field 112N*. A light soil from the University Farm containing 10.5 per cent. coarse silt, 8.5 per cent. fine silt and 2.5 per cent. clay.
- (7) *Field 27A*. A heavy soil from the University Farm.
- (8) *A Clay Subsoil* taken during drainage excavations in the grounds of the University.

Glass apparatus used for flocculation experiments was previously cleaned with chromic acid. The test tubes used were all of the same size—20 c.c. of water formed a column of the same height in each. All experiments have been made in duplicate at least.

1. (a) A preliminary observation on the relative stability of clay in neutral and in alkaline suspension was made as follows. 10 gms. of a clay soil were stirred with water in a beaker and allowed to sediment in

<sup>1</sup> These soils were kindly supplied to the writer by Mr G. W. Robinson, University College of North Wales, Bangor.

a column of water 8.5 cms. high, as in the mechanical analysis of soils except that the soil was not previously treated with acid and no ammonia was added. After 24 hours the clay suspension was decanted, 50 c.c. were placed into each of two stoppered cylinders of 1 inch diameter. To the contents of one cylinder (A) 1 c.c. of  $N\text{NH}_4\text{OH}$  was added, and 1 c.c. of distilled water to the contents of the other (B). To each was then added 1 c.c.  $N\text{Ca}(\text{NO}_3)_2$ . The cylinders were similarly shaken by inverting five times, and were then allowed to stand in uniform lighting. After 10 minutes floccules could be seen in A by means of a lens, but not in B. After 1 hour the difference was visible to the naked eye, and in  $1\frac{1}{2}$  hours, when flocculation was just commencing in B, the far superior flocculation in A could be seen at a glance. This experiment was repeated with the same soil which had been treated with 5 per cent.  $\text{HCl}$ , washed, and dried in the oven: it was also repeated with the treated and untreated soil, the cylinders being kept in a closed thermostat at  $18^\circ\text{C}$ . In all these repetitions the results were substantially the same.

(b) 10 gms. of each of the soils, and of the subsoil, enumerated above, were allowed to sediment for 24 hours, without previous treatment, and without the addition of ammonia, in a column of water 8.5 cms. high. The weight of residue obtained by the evaporation of an aliquot portion of each of the decanted suspensions was determined and the suspensions were adjusted by dilution to contain 80 mgms. of solid in 100 c.c. Fifteen c.c. of each of the equalized suspensions were pipetted into a series of eight medium-sized test tubes (C) and another 15 c.c. of each into a similar series of eight test tubes (D). To the contents of each tube in series C, 1 c.c.  $N/1\text{NH}_4\text{OH}$  was added, and 1 c.c. of distilled water to each of the tubes in series D. The contents of the tubes were mixed by inversion, 1 c.c.  $N/5\text{Ca}(\text{NO}_3)_2$  was added to each of the 16 tubes, which were again inverted and allowed to stand in a closed thermostat at a temperature of  $18^\circ\text{C}$ . Excepting the Palaeozoic Silt Loam and the Anglesey Medium Loam, the contents of the tubes in series C flocculated before their respective partners in series D. In series C flocculation was clearly visible in the suspensions from English soils after 2 hours, but only commenced in series D after 4 hours. The suspensions from the Welsh soils began to flocculate after 4 hours and there was little or no difference between the alkaline and neutral suspensions. (The beginning of flocculation was recorded when distinct floccules were visible in a tube, a control series containing no  $\text{Ca}(\text{NO}_3)_2$  being used for comparison.)



(c) In order to ascertain whether variation of alkalinity had any effect upon flocculation, a series of seven tubes each containing 15 c.c. of a clay suspension was arranged, and  $\text{NH}_4\text{OH}$  added in amounts varying from 0 in the first tube to 5 c.c.  $N \text{ NH}_4\text{OH}$  in the seventh. The volumes and heights were equalized with distilled water, 1 c.c.  $N/5 \text{ Ca}(\text{NO}_3)_2$  added to each tube and the tubes shaken and allowed to stand. The alkaline suspensions all flocculated before the neutral suspension, but there was no appreciable difference between one alkaline tube and another.

(d) In order to examine the effect of reaction on a less highly dispersed clay system than those described above, 0.5 gm. of a clay subsoil was shaken in a test tube with 25 c.c. of distilled water, and allowed to settle for 2 minutes when the suspension was decanted and divided into two portions of 10 c.c. each. To one of these 0.2 c.c.  $N \text{ NH}_4\text{OH}$  was added and 0.5 c.c.  $N/5 \text{ Ca}(\text{NO}_3)_2$  was added to each. The alkaline suspension flocculated forthwith and was almost clear in 5 minutes; the neutral suspension was still opaque after 10 minutes.

(e) Hall and Morison record that the addition of acid or alkali had no effect on the natancy of suspensions of silica. Using Kahlbaum silicic anhydride, the present writer has also found no difference in the rate of settlement consequent upon alkalinity or acidity. But under the influence of calcium nitrate the difference due to alkalinity is most marked. Two portions of silica each weighing 2 gms. were placed in glass jars, and shaken, using a ground glass cover, with 75 c.c. distilled water. To one jar 1 c.c.  $N \text{ NH}_4\text{OH}$  was added and 1 c.c.  $N \text{ Ca}(\text{NO}_3)_2$  was added to each. The alkaline suspension flocculated in 10 minutes while the other was apparently unaffected after 8 hours.

2. The effect of the presence of small amounts of colloidal silica on particles was examined synthetically. In one experiment 0.3 gms. of a sample of oxide of iron, in a very finely divided state, was shaken with 20 c.c. of water, and in another tube the same weight of the oxide of iron was shaken with 20 c.c. of a colloidal solution of silicic acid (freed from electrolytes by dialysis) containing 0.03 gm.  $\text{SiO}_2$  in a litre. The suspensions were each divided into two parts contained in small test tubes. Using first the aqueous suspension 0.2 c.c.  $N \text{ NH}_4\text{OH}$  was added to one part and 1 c.c.  $N/5 \text{ Ca}(\text{NO}_3)_2$  was added to both parts. The particles settled similarly in both tubes and settlement was complete in 15 minutes: there was no appearance of floccules, the settlement being similar to the settlement of the oxide in water alone, without  $\text{Ca}(\text{NO}_3)_2$ . Using next the siliceous suspension, it was found that the

ammoniacal portion showed a definite and immediate formation of floccules and settled in 7 minutes while the neutral suspension was opaque for 30 minutes. When the dilute silicic acid sol without any suspended solid was used, no visible precipitation resulted from the addition of calcium nitrate in either neutral or ammoniacal solution even after standing for 3 hours. Very small amounts of silicic acid in conjunction with suspended matter appear to exert an important influence on the system.

3. In order to observe the relative effects of hydroxide, bicarbonate and nitrate of calcium on soil flocculation, a solution of calcium hydroxide was made up, with the usual precautions for excluding  $\text{CO}_2$ , and its strength adjusted to  $N/25$ . A portion of this solution was then converted into bicarbonate. Three similar suspensions of the subject of examination were prepared and treated respectively with 5 c.c. of the  $\text{Ca}(\text{OH})_2$ , the  $\text{Ca}(\text{HCO}_3)_2$ , and a  $N/25$   $\text{Ca}(\text{NO}_3)_2$  solution. When suspensions, each containing 0.5 gm. of the clay subsoil in 15 c.c. water were used there was an immediate and marked flocculation resulting from the addition of the hydroxide, while the bicarbonate and nitrate produced much slower flocculation. The times of settlement of the clay in one experiment were  $\text{Ca}(\text{OH})_2$ , 2 minutes;  $\text{Ca}(\text{HCO}_3)_2$ , 14 minutes;  $\text{Ca}(\text{NO}_3)_2$ , 10 minutes. Similarly with a clay drift soil the hydroxide proved to be a far better flocculant than the bicarbonate or nitrate.

When 0.3 gm. of the oxide of iron suspended in 20 c.c. of the dilute silicic acid sol, as previously described, was treated with calcium hydroxide precipitation was immediate; with the bicarbonate and nitrate it was very much slower.

With a silt soil, the flocculation by the hydroxide was very much inferior to that of the nitrate or bicarbonate. When suspensions of soil from Field 113 made by shaking 2 gms. with 15 c.c. water were used, the greater flocculation by the nitrate was apparent in 10 minutes, and became more apparent on standing. After 2 hours the nitrate treated suspension had nearly settled while the hydroxide treated suspension was still opaque. In pursuance of this, Exp. 1 (*d*) was repeated using the fine silt fraction (unignited) separated by the ordinary process of mechanical analysis in place of the clay. The neutral suspension flocculated in 15 minutes; the alkaline suspension remained opaque after an hour. This experiment, both with fine silt and with clay, was repeated very many times, and there was always a strong and consistent indication that clay is most stable in neutral suspension (i.e. near its isoelectric point) while the reverse is true of silt.

5. It had been noticed in the course of these observations that the superior flocculation of a clay soil in alkaline suspension was more marked when the bulk of liquid for any given weight of soil was small, than when it was large. In pursuance of this observation experiments were carried out as follows. A series of eight test tubes was arranged with the tubes in four pairs, and 2 gm. of the soil under examination was placed into each of the eight tubes, 20 c.c. of water were then added to each tube of the first pair, 10 c.c. to each of the second, 5 c.c. to each of the third and 2 c.c. to each of the fourth. One tube in each pair, then received 1 c.c.  $NH_4OH$  (the other receiving 1 c.c. distilled water) and each tube received 1 c.c.  $N/5 Ca(NO_3)_2$ . The four volumes were therefore 22 c.c., 12 c.c., 7 c.c. and 4 c.c.

When the clay soil was used, the difference between the flocculation of the alkaline suspension and the flocculation of the corresponding neutral suspension was distinctly greater in the smaller volumes than in the larger. The observation is admittedly a difficult one to make as it is the observation (as distinct from measurement) of a second order of difference, but confirmation was found when the soil of Field 27A (Garforth) was used. In the two smaller volumes (4 c.c. and 7 c.c.) flocculation was better in the alkaline suspension; in 12 c.c. it was slightly better in the neutral suspension; in 22 c.c. the neutral suspension was nearly clear before flocculation could be seen at all in the other. In the highly dispersed system the silt asserted its properties, while in more concentrated systems the emulsoid character of the clay prevailed.

#### DISCUSSION.

The foregoing experiments show that alkalinity decreases the flocculating effect of the calcium ion on suspensions of silt. Calcium nitrate is a better flocculant of silt when the suspension is neutral than when it is alkaline, and calcium nitrate is more efficient than the hydroxide. This result is qualitatively in accordance with prevailing conceptions of flocculation. It is generally held that particles in suspension are flocculated when their electric charge is neutralized and they are thus brought to their "isoelectric point"; and, although the mechanism of the action is still very much discussed, it is known that the presence of hydroxyl ions increases the negative charge carried by particles suspended in water. Calcium ions and hydroxyl ions thus work in opposition, the former tending to bring the particles to their isoelectric point and thus cause their flocculation, the latter tending to increase their negative charge, i.e. to remove them from their isoelectric

point. The greater difficulty of flocculating the particles in the presence of hydroxyl ions is therefore a fact which squares with current teaching on the mechanism of flocculation, and from the standpoint of this teaching the flocculation of silt, as examined in the experiments described above, may be regarded as normal.

The effect of alkalinity on the flocculation of clay, however, appears to present quite another case, for here the presence of hydroxyl ions facilitates the flocculation by calcium ions. Calcium nitrate is a poor flocculant of clay in neutral suspensions, but after the addition of a trace of ammonium hydroxide to the suspension the calcium salt flocculates the clay very rapidly. Similarly calcium hydroxide is found to be a much better flocculant of clay than a neutral calcium salt.

In endeavouring to estimate the significance of these opposite effects of alkalinity on clay and on silt it seems important to take into consideration the general recognition of two classes of colloids. Graham divided his colloidal substances into those which form compounds with water and those which do not. In most of the subsequent schemes of classification regard has been given to two groups which roughly coincide with those described by Graham. From much the same view point as that taken by Graham, namely the affinity or lack of affinity between the disperse phase and the dispersion medium, Freundlich<sup>1</sup> and others distinguish between "lyophilic" and "lyophobic" colloidal solutions. Henri<sup>2</sup> discriminates between stable and unstable colloids; Noyes<sup>3</sup> describes gelatinizing types (colloidal solutions) and non-gelatinizing types (colloidal suspensions). The classification of Ostwald<sup>4</sup> and von Weimann<sup>5</sup> who distinguish between "emulsoid" and "suspensoid" colloids is doubtless the most familiar, although the attempt to make it rigid by defining emulsoids as liquid-liquid systems and suspensoids as solid-liquid systems fails; Zsigmondy<sup>6</sup>, for instance, points out the anomalous position of mercury sols and of protected gold sols resulting from these definitions. All these schemes of classification are little more than descriptive; but, while it may at present elude scientific definition and terminology, a manifest difference exists, at least superficially, between the gelatinizing, viscous colloids—such as silicic acid and the gums, which are not easily coagulated by electrolytes and which are readily able to absorb water—and the non-gelatinizing, limpid colloids.

<sup>1</sup> *Kapillarchemie*, 1909.

<sup>2</sup> *Journ. Amer. Chem. Soc.* 1905, 27, 2, 85.

<sup>3</sup> *Grundriss der Kolloidchemie*, 1909.

<sup>4</sup> *Kolloidchemie*, 1912.

<sup>5</sup> *Zeitsch. für phys. Chem.* 1905, 51, 19.

<sup>6</sup> *Grundzüge der Dispersionschemie*, 1911.

such as the metallic sols, which are rapidly and easily coagulated and which exhibit no marked tendency to absorb water and swell. For our present purpose we may tentatively distinguish between these two groups, using the prevalent terms "emulsoid" and "suspensoid."

Now the enhanced flocculation of clay brought about by alkalinity of the medium of suspension has no analogy among the suspensoid colloids. The suspensoids appear to be invariably precipitated at, or at any rate near, their isoelectric point, and the precipitation of negatively charged suspensoids and suspensions is hindered by the presence of hydroxyl ions which increase the negative charge. Among the emulsoid colloids, however, there is less uniformity. The electric charge appears to be more accidental and less characteristic, and in some cases it may be reversed by altering the reaction of the medium. Among these "gelatinizing," "viscous," "lyophilic" colloids may be found some which, like clay, are more easily precipitated from alkaline than from neutral solution. Flemming<sup>1</sup> found the rate of gel-formation of silicic acid was greatest at a small hydroxyl ion concentration (although the sol appears to be electrically neutral at a small hydrogen ion concentration) and it is easy to show that pure dialysed silicic acid is precipitated very slowly by calcium or barium chloride, but is immediately precipitated by these salts if a trace of ammonium hydroxide is first added to the sol. Egg albumin and some other emulsoids behave in a similar manner.

It seems likely, therefore, that the clay particles of soil are protected by some emulsoid material, such as silicic acid. The protection of colloids has been a recognized phenomenon for many years, and a suspension or suspensoid which is protected by emulsoid material is essentially a system possessing the properties of the protective colloid. That siliceous and organic materials may function as protectors of the soil particles is manifest, and that such protection does occur is indicated by the greater amount of electrolyte required to flocculate soil clay than is required to flocculate kaolin<sup>2</sup>. Also, it seems reasonable to suppose that if a system of particles of all sizes is protected, the protection of the smallest particles may be sufficiently great to cause the properties of the protecting colloid to predominate, while with the larger particles their suspensoid nature may still prevail. The amount of silicic acid required to produce a system more easily precipitated from alkaline than from neutral suspension was examined synthetically. In the

<sup>1</sup> *Zeitsch. phys. Chem.* 1905, **51**, 150.

<sup>2</sup> Wolcott, M. L., *Soil Sci.* 1916, **1**, 585.

experiment described 0.6 mgm.  $\text{SiO}_2$  was found to be sufficient to protect 300 mgm. of finely divided ferric oxide.

It is interesting to notice that the enhanced flocculation of clay consequent upon the addition of alkali to the suspension is very much less marked in the Welsh soils. The general description of these soils by Robinson<sup>1</sup> and the earlier description of the Craibstone soil by Hendrick and Ogg<sup>2</sup> have reduced the tendency to draw general conclusions respecting soil phenomena from limited observations. The fundamental difference in the composition of these Welsh and Scotch soils from that of English soils has been shown to involve other fundamental differences, and generalizations which apply to English soils are sometimes found not to apply to these. It seemed therefore desirable to examine the stability of their clay fractions under the influence of calcium ions, in neutral and in alkaline suspension: and the result seems to show that the protective colloids in these soils are quite different from those in English soils. The clay of the Welsh soils behaves, however, differently from the silt, for ammonium hydroxide has no marked retarding effect upon its flocculation.

The action of calcium hydroxide and of calcium bicarbonate as flocculants of clay has generally been regarded as anomalous. On the one hand it has been taught that alkalies deflocculate clay, and on the other hand it has long been known that the above named alkaline compounds of calcium are flocculants *par excellence*. If the emulsoid character of clay is admitted then calcium hydroxide is seen to be an ideal flocculant, for the calcium ions and the hydroxyl ions are not working in opposition, but in collaboration. The hydroxyl ions remove the emulsoid from its isoelectric point and thereby render it less stable, and the calcium ions then coagulate the unstable emulsoid.

The difficulty which has existed in explaining the flocculating action of calcium hydroxide has sometimes resulted in the statement that pure calcium hydroxide does not flocculate clay. This teaching is probably true when unprotected suspensoids or suspensions are concerned. It is also undoubtedly true of the action of calcium hydroxide on some of the larger soil particles, but it is difficult to believe that only in the presence of carbon dioxide, and after its conversion into calcium bicarbonate, does lime flocculate soil clay. When calcium hydroxide and calcium bicarbonate are added in equivalent amounts to similar clay suspensions, there is a quicker and greater flocculating action from the hydroxide than from the bicarbonate. Further, the flocculating action

<sup>1</sup> *Journ. Agric. Sci.* **8**, 338.

<sup>2</sup> *Ibid.* **7**, 458.

of calcium hydroxide is much more marked than that of calcium nitrate in equivalent amount. Ferric oxide, artificially protected by silicic acid, behaved similarly to soil clay, showing greater flocculation with calcium hydroxide than with either calcium bicarbonate or nitrate.

The laboratory examination of flocculation phenomena is usually carried out by methods involving the use of a suspension in a column of water. The validity of such a method may reasonably be questioned. It cannot be held, without investigation, that the relative effects of electrolytes upon suspended soil particles is correctly indicative of their relative effects on the soil *in situ*. Experiments were therefore carried out in which observations were made of the influence of the bulk of water in which a given weight of soil is suspended, upon the relative effects of calcium hydroxide and calcium nitrate. The results show that when the bulk of water in which a given weight of a clay soil is suspended, is large, the nitrate is nearly as good a flocculant as the hydroxide, whereas the hydroxide is much superior when the bulk of water is small. By a kind of extrapolation the relative effects of electrolytes, or of the same electrolyte in different conditions of reaction, may reasonably be judged. The most striking result obtains from a silt soil containing large amounts of clay (Field 27A, Garforth). In a small bulk of water the alkaline flocculant is superior: in a large bulk it is very inferior.

Now it is significant that decreasing the bulk of water in which a soil is suspended greatly enhances the efficacy of an alkaline flocculant. It has already been observed that alkalinity facilitates the flocculation of clay but militates against the flocculation of particles of higher dimensions. When the bulk of water is lessened, i.e. when the clay and the larger particles are forced nearer together, the total system behaves more like clay and less like silt. When the bulk of water is increased, i.e. when the particles are brought further apart, the total system behaves more like silt and less like clay. It therefore appears that clay—itself a protected colloid—functions in the soil as a protective colloid, and that by suspension in a large bulk of water the clay may be successfully removed from the silt to allow the silt to function in an unprotected state. Siliceous and organic emulsoids appear to protect the clay and the clay appears to protect the silt.

The general tendency for smaller particles to assemble around larger ones, when a suspension containing particles of different sizes is flocculated, is established in the work of colloid chemists. "The electrolytic coagulation of colloids which contain particles of various sizes progresses by the condensation of small particles on those of larger size

and not by the coalescence of particles of the same size<sup>1</sup>." A clay suspension is flocculated much more rapidly when larger particles are present, provided the proportion of the larger particles to the clay is not too great and provided also that the bulk of water in which the system is suspended is not too large.

If in the physical constitution of the soil the clay functions, not only as a protected colloid, but also as a protective colloid of larger particles, the difficulty of ameliorating the texture of fine silt soils is apparent, for in these soils the fine silt presents so large a surface that its protection by such amounts of clay as are commonly found in silt soils is inadequate. The possible amelioration of the texture of fine silt soils might therefore be found in one of two treatments; either in the use of non-alkaline flocculants or in the application of emulsoid materials before lining. Laboratory experiments show that calcium nitrate is more efficient than the hydroxide and also that treatment with alkaline silicic acid sols greatly enhances the flocculation of these soils by calcium salts. It is intended to investigate this matter under field conditions.

There has long been a general recognition of the peculiar and predominant position of the clay fraction of soil particles, and since the researches of Way on absorption the evidence for a specific recognition has been accumulating. In recent work, for instance, the reabsorption of phosphoric acid, after its extraction from the soil, has been shown by Russell and Prescott<sup>2</sup> to vary with the amount of the clay fraction; and on the purely physical side, Keen<sup>3</sup> has shown that the evaporation of water from soils is a complex phenomenon when compared with the evaporation of water from sand, silt or even china clay, but that "when the colloidal properties of the soil fraction 'clay' are destroyed the evaporation curve... becomes identical with that given by 'sand' or 'silt.'" Now the different—and not only different but entirely opposite behaviour of clay from that of silt which is described above seems strongly to indicate that the peculiarities of clay in relation to other particles arise not only from colloidal properties but from a special category of colloidal properties. Future developments in the classification of colloids may give a more scientific place and nomenclature to these special properties: for the present the predominant terminology of the text books is adopted, and by reason of the analogy between the behaviour of clay and of silicic acid which has been referred to it is

<sup>1</sup> Barton, E. F., *The Phys. Props. of Colloidal Solns.*, 1916.

<sup>2</sup> *Journ. of Agric. Sci.* **8**, 65.

<sup>3</sup> *Ibid.* **6**, 456.



submitted that clay is an "emulsoid" colloid and imposes its properties as such upon the soil.

#### SUMMARY.

"Silt," like most insoluble substances, when suspended in water is most easily flocculated by calcium salts when the suspension is neutral. The addition of alkali stabilizes the suspension and renders flocculation more difficult. Soil "clay," however, behaves in an opposite manner, and is precipitated from alkaline suspensions more readily than from neutral suspensions. In this behaviour clay resembles silicic acid and some other members of the so-called "emulsoid" colloids, and it is suggested that the clay particles are protected by such colloids and thus behave as an "emulsoid" and not as a "suspensoid."

If this is true then the action of lime, which being alkaline nevertheless flocculates clay, is seen to be in accordance with the facts of colloid chemistry.

The view is advanced and some experimental support of it is described, that clay, as an "emulsoid," protects the larger particles which by themselves are "suspensoid." The soil aggregates are conceived as having large nuclei surrounded by particles which become smaller from the centre of the aggregate outwards, the clay ultimately imposing its "emulsoid" nature on the whole aggregate, and on the whole soil in normal cases. Fine silt soils are not flocculated by calcium hydroxide on account of the inefficiency of the relatively small amount of "emulsoid" clay to protect the large "suspensoid" surface exposed by the fine silt.

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## THE DIGESTIBILITY OF STRAW AFTER TREATMENT WITH SODA.

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THE use of straw as fodder is beset by the double difficulty that on the one hand its bulky character seriously limits the extent to which it can be consumed by the animal, whilst on the other hand its tough and fibrous nature entails such a heavy expenditure of energy to secure the high degree of comminution and further preparation essential for effective action of the digestive agents that only a comparatively small surplus of energy remains over to serve productive nutritional ends. Thus it was found by Kellner and Köhler<sup>2</sup> in the case of oat straw that of the total energy contained in the straw only 35·8 per cent. was usefully digested, whilst only 12·9 per cent. could be applied after digestion to productive purposes. For wheat straw the corresponding proportions were 31·1 per cent. and 5·5 per cent. respectively. These may be contrasted with the proportions of 49 per cent. and 20·7 per cent. respectively found by the same observers for meadow hay; and the proportions of 74·9 per cent. and 45·9 per cent. respectively found by Armsby and Fries<sup>2</sup> for maize meal.

These figures bring out clearly the disadvantage from which crude straw suffers as a feeding stuff in that not only does it show a low digestibility, but even the digested portion is not as efficiently utilised as in the case of the material digested from other foods.

The principal reason for the low digestibility of straw undoubtedly lies in the fact that the digestible matters are embedded in indigestible, lignified tissue whereby they are protected to a considerable extent from the action of the digestive juices. Frequent attempts have been made to overcome this difficulty by grinding the straw to meal or softening it by fermentation, the latter being the basis of the common farm practice of feeding chopped straw with pulped roots or chaffed greenstuff.

<sup>1</sup> The work was carried out in the Institute for Research in Animal Nutrition of this Department.

<sup>2</sup> Vide Armsby, *The Nutrition of Farm Animals*, 1917, p. 660.

When measured in terms of digestibility, however, the improvement effected by these processes is not very great. The undoubted benefit realised in practice by the fermentation processes lies rather in the increased palatability of the straw, which secures heavier consumption.

No real headway was made in efforts to increase the digestibility and nutritive efficiency of straw until recourse was had to chemical methods of removing the incrusting substances by treatment with acid or alkali. Of these the most successful have been the processes in which the straw is treated with soda or other alkaline liquors as in the preparation of straw pulp for paper making.

Attention was first directed to the possibilities of this treatment for feeding purposes by the experiments of Kellner published in 1900 which showed that straw pulp prepared for paper making by the sulphite process was highly digestible by ruminants (88.3 per cent.) and but little inferior in nutritive value to an equal weight of starch. Inspired by these results F. Lehmann examined the possibilities of adapting the process for use on the farm and in 1902 published particulars of a process for treatment of straw with caustic soda solution for which he claimed very satisfactory results.

In Lehmann's process 100 kgms. straw was boiled with 200 kgms. water and 2.4 kgms. caustic soda in large iron boilers for six hours at a pressure of 4-5 atmospheres, after which the product was washed with water until free from alkali and well pressed. By this treatment the digestibility of the straw was found to be increased by about one-half.

The process attracted much attention in Germany at the time and several plants were installed on farms, but it was apparently found uneconomical at the low level of values then obtaining, and despite improvements effected from time to time little further headway was made until the economic upheaval occasioned by the war forcibly directed attention, especially in Germany, Austria and Scandinavian countries, to the necessity of utilising home-grown fodder supplies to the utmost possible advantage.

Early in the war the German Government, faced with the impending failure of the supply of concentrated feeding-stuffs, decided to take measures to establish on a large scale the manufacture of a digestible fodder from straw by the soda process, the technique of which was rapidly being improved. By the end of the war numerous factories were at work with a large output of "straw concentrate".

<sup>1</sup> For a summary of the developments of the process during the war cf. *Journal of the Ministry of Agriculture*, 1919, 26, 15.

In this country fortunately the general fodder situation never became so serious as to necessitate such drastic measures, but as the import of feeding-stuffs became more and more difficult and restricted it became necessary to take thought as to the possibility of the more efficient utilisation of the available supplies of home-grown feeding stuffs. Accordingly in 1917 at the request of the Board of Agriculture (Food Production Department) the writer undertook an examination of the practical possibilities of the soda process for use in this country under the conditions then prevailing.

It was realised that in view of the current situation there could be no question of developing the manufacture on the factory scale as in Germany and that the most that would be practicable would be a comparatively simple process that might be carried out on the farm, with ordinary farm appliances, and involving a minimum requirement for soda and fuel.

It was also desired if possible to avoid the necessity for washing the product free from soda, a process which is tedious and requires ample water supplies. If these ends could be secured the process might then be carried out on any farm provided with appliances for steaming food.

In the heating of the straw a certain amount of acid material is produced so that by regulating the proportions of straw and soda it is possible to obtain a product of neutral reaction which might then perhaps be fed to the animals without washing. A number of preliminary tests were therefore made in the laboratory in order to determine the conditions requisite for obtaining such a product.

These experiments indicated that the desired end could be secured by soaking chopped straw thoroughly in a 1.5 per cent. solution of soda and then steaming for one hour, and a method of preparation for use on the farm was accordingly devised on this basis and tested at the Manor Farm, Garforth (Experimental Farm of the University of Leeds).

In this method the chopped straw was thoroughly soaked overnight in a 1.5 per cent. solution of caustic soda, then well drained and transferred to the farm "steamer," which consists of a vertical iron boiler, with loose cover and fitted with a steam-pipe delivering steam near the base. Steam was blown through until the whole mass was raised to the boil, and the steaming then continued for one hour. The treated straw was then removed, thoroughly drained, allowed to cool and used for feeding.

After preliminary trials had shown that stock could be induced to consume the product satisfactorily, arrangements were made for digestibility trials with two sheep, the particular straw used being oat straw.

In order to determine whether the presence of the soda exercised any influence upon the digestibility of the treated straw, a quantity of the latter was washed with water until free from alkali and the digestibility of the washed product determined separately. In the following account these two products are referred to as "Crude Concentrate" and "Washed Concentrate" respectively.

In order to ensure an adequate supply of protein an addition of casein was made to the ration in the first period of the experiment (Untreated Straw), but in the later periods this was replaced by linseed cake.

The periods, each of 14 days' duration, with an interval of one week between each, were arranged as follows:

Period I. Untreated Straw and Casein.

„ II. Crude Concentrate and Linseed Cake.

„ III. Untreated Straw and Linseed Cake.

„ IV. Washed Concentrate and Linseed Cake.

A little salt was also added to the ration in Periods I, III and IV.

The average composition of the straw products used is given below:

|                    | Moisture | Crude protein | True protein | Ether extract | Nitrogen-free extractives | Crude fibre | Ash  | Sand |
|--------------------|----------|---------------|--------------|---------------|---------------------------|-------------|------|------|
|                    | %        | %             | %            | %             | %                         | %           | %    | %    |
| Untreated straw    | 12.75    | 2.04          | 1.69         | 1.76          | 38.24                     | 40.58       | 4.63 | 1.62 |
| Crude concentrate  | 75.61    | 0.31          | 0.29         | 0.38          | 7.14                      | 14.49       | 2.07 | 0.13 |
| Washed concentrate | 47.73    | 0.63          | 0.63         | 0.76          | 14.07                     | 34.73       | 2.08 | 0.62 |

*Percentages on Dry Matter.*

|                    |   |      |      |      |       |       |      |      |
|--------------------|---|------|------|------|-------|-------|------|------|
| Untreated straw    | — | 2.34 | 1.94 | 2.02 | 43.83 | 46.51 | 5.30 | 1.86 |
| Crude concentrate  | — | 1.27 | 1.19 | 1.56 | 29.27 | 59.41 | 8.49 | 1.63 |
| Washed concentrate | — | 1.20 | 1.20 | 1.45 | 26.90 | 66.45 | 4.00 | 1.20 |

The soda treatment obviously caused a loss of crude protein, ether extract and nitrogen-free extractives, with consequent enhancement of the proportion of crude fibre. The total loss of dry matter in the preparation of the "crude concentrate" was 20 per cent., this rising to 33.5 per cent. on washing to get the "washed concentrate."

The digestion coefficients arrived at are given on p. 441.

The proportions of protein in the straw products were too small to permit of their digestibility being measured, the recorded results being indeed almost invariably negative.

<sup>1</sup> These differ slightly from the averages given in a preliminary notice in the *Journal of the Board of Agriculture*, 1919, 26, 20, but the general conclusions there drawn are in no way affected by the changes.

Apart from this the results are fairly consistent and in very good agreement with those recorded by German experimenters.

|                           | UNTREATED STRAW |              |           | CRUDE CONCENTRATE |              |           |
|---------------------------|-----------------|--------------|-----------|-------------------|--------------|-----------|
|                           | Sheep 1<br>o    | Sheep 2<br>o | Mean<br>o | Sheep 1<br>o      | Sheep 2<br>o | Mean<br>o |
| Total organic matter ...  | 51.2            | 43.4         | 47.3      | 74.5              | 72.9         | 73.7      |
| Crude protein ... ..      | ?               | ?            | ?         | ?                 | ?            | ?         |
| True protein ... ..       | ?               | ?            | ?         | ?                 | ?            | ?         |
| Ether extract ... ..      | 43.6            | 43.6         | 43.6      | 27.1              | 22.2         | 24.7      |
| Nitrogen-free extractives | 43.4            | 35.7         | 39.6      | 66.6              | 59.1         | 62.9      |
| Crude fibre ... ..        | 63.6            | 56.5         | 60.1      | 86.7              | 88.1         | 87.4      |

|                           | WASHED CONCENTRATE |              |           | LINSEED CAKE |              |           |
|---------------------------|--------------------|--------------|-----------|--------------|--------------|-----------|
|                           | Sheep 1<br>o       | Sheep 2<br>o | Mean<br>o | Sheep 1<br>o | Sheep 2<br>o | Mean<br>o |
| Total organic matter ...  | 74.6               | 69.8         | 72.2      | 76.2         | 76.6         | 76.4      |
| Crude protein ... ..      | ?                  | ?            | ?         | 84.8         | 81.5         | 83.2      |
| True protein ... ..       | ?                  | ?            | ?         | 82.2         | 79.2         | 80.7      |
| Ether extract ... ..      | 25.1               | 34.6         | 29.9      | 90.8         | 92.6         | 91.7      |
| Nitrogen-free extractives | 68.9               | 58.7         | 63.8      | 77.6         | 79.5         | 78.6      |
| Crude fibre ... ..        | 84.7               | 81.9         | 83.3      | 18.4         | 19.9         | 19.2      |

It may be noted first that there is no appreciable difference of digestibility evident between the "crude concentrate" and the "washed concentrate," but both show a very substantial improvement on the original straw, the digestibility of the organic matter as a whole being increased by fully one-half. This improvement is evident in both the nitrogen-free extractives and the crude fibre, the two items which must primarily determine the nutritive value of straw products.

With a knowledge now of the composition and digestibility of these straw products we are in a position to assess the actual enhancement of nutritive value that has been achieved by the treatment. Adopting the method developed by Kellner we arrive at the following as the Starch Equivalents of 100 lb. dry matter in the untreated and treated products respectively:

|                        | Maintenance<br>lb. | Production<br>lb. |
|------------------------|--------------------|-------------------|
| Untreated straw ...    | 48.1               | 29.6              |
| Crude concentrate ...  | 71.7               | 36.9              |
| Washed concentrate ... | 73.9               | 35.1              |

These figures indicate that for maintenance purposes the dry matter of the treated straw has roughly one and a half times the value of the original dry matter, whilst for production purposes its value is nearly double.

It remains to be seen whether this enhancement of the value of the dry matter is sufficient to compensate for the loss of dry matter involved in the treatment, which, as previously mentioned, amounted to 20 per cent. in the case of the "crude concentrate" and 33·5 per cent. in the case of the "washed concentrate."

*Yield and Value of Produce from 100 lb. Straw Dry Matter.*

|                        | Amount dry<br>matter<br>lb. | Starch equivalent  |                   |
|------------------------|-----------------------------|--------------------|-------------------|
|                        |                             | maintenance<br>lb. | production<br>lb. |
| Straw ... ..           | 100                         | 48·1               | 20·6              |
| Crude concentrate ...  | 80                          | 57·4               | 29·5              |
| Washed concentrate ... | 66·5                        | 49·1               | 23·3              |

These figures show that there is a clear gain of nutritive efficiency in each case, although in the case of the "washed concentrate" the gain is not very great.

The economy of the process must naturally vary from time to time with fluctuations in the relative value of straw, soda and fuel. By bringing the strength of the residual liquor in the soaking tank up to 1·5 per cent. after each treatment it may be made to serve for several batches of straw and an appreciable economy of soda thereby effected. This point was not specifically investigated, but it may be taken that for every 100 lb. of straw treated, about 5 lb. of soda will be used up.

If we take for example a price of £5 per ton for straw with 20·6 per cent. starch equivalent (production), the value per unit of starch equivalent is practically 5s. On this basis the value of a ton of the "crude concentrate" in "straw-dry" condition would be roughly £7. 7s., to produce which 24 cwt. of straw valued at £6 would be used, leaving a balance of 27s. per ton of product to cover working costs and depreciation of plant.

Since these experiments were planned improvements have been effected in the soda process, the most important being that devised by Beckmann in which heating is entirely dispensed with, the straw being simply soaked for a period of not less than six hours in a cold solution of caustic soda. Digestion trials have shown that this process gives a product equal in nutritive value to those obtained by the processes involving heating with soda.

All these processes suffer from the practical disadvantage that caustic soda is troublesome to handle and not without risk for labour ignorant of its properties. This difficulty might be overcome by using a mixture of lime and sodium carbonate, or possibly by using sodium carbonate

alone. Experiments are quoted by Magnus<sup>1</sup> which indicate that boiling with sodium carbonate may be as effective for practical purposes as treatment with sodium hydroxide.

There is obviously need for much further investigation of the possibilities of soda treatment before a final opinion can be expressed as to its merits for introduction into farm practice.

#### EXPERIMENTAL.

In order to discover the most satisfactory conditions for treating the straw so as to obtain the best product with a minimum expenditure of time and material, the following preliminary experiments were conducted in the laboratory.

##### *Volume of Liquor retained by Straw in drained condition.*

Very finely chopped oat straw was used and it was found that, if such material was left in a funnel overnight in contact with an excess of 1.5 per cent. cold aqueous sodium hydroxide and the excess liquid allowed to drain away in the morning, 100 gms. of the straw absorbed 370 c.c. of the soda solution. In all the subsequent experiments, therefore, unless otherwise stated, the materials were used in this proportion.

##### *Influence of Duration of Heating on Composition of Straw.*

Twenty-gram lots of the straw were heated in steam with 74 c.c. of the 1.5 per cent. soda solution for one, two and three hours respectively at atmospheric pressure. The resulting products were practically neutral to litmus paper, and on them determinations of crude fibre, soluble organic matter and ash were made, the results, expressed as percentages on the dry matter, being as follows:

|                      | Crude<br>fibre<br>% | Soluble organic<br>matter<br>% | Ash<br>% |
|----------------------|---------------------|--------------------------------|----------|
| Original straw       | 48.32               | 6.53                           | 7.73     |
| After steaming 1 hr. | 45.68               | 18.18                          | 13.27    |
| " " 2 hrs.           | 46.14               | 18.87                          | 13.35    |
| " " 3 hrs.           | 46.05               | 19.22                          | 13.10    |

Thus it may be seen that, prolonging the steaming to three hours had practically no effect over the one hour's steaming on the composition of the final product, except possibly to give a slight increase in the amount of soluble organic matter formed.

<sup>1</sup> *Die Theorie und Praxis der Strohaufschliessung* (Paul Parry, Berlin, 1919).



*The Digestibility of Straw**Influence of Temperature on Digestion.*

Steaming at a higher temperature was then tried, the materials being heated in a steam autoclave at 115° C. In this experiment the volume of alkali used was increased in one case and its concentration in another. The results for crude fibre except in the case where a large excess of alkali was used are of the same order as those from the previous experiment. In all cases the percentage of soluble organic matter in the product was considerably increased.

*20 gms. of straw heated in an autoclave at 115° C.*

|                                    | Crude<br>fibre<br>% | Soluble organic<br>matter<br>% |
|------------------------------------|---------------------|--------------------------------|
| + 74 c.c. (1.5 % NaOH) for 1 hr.   | 45.38               | 23.84                          |
| + 74 c.c. (1.5 % NaOH) for 2 hrs.  | 48.66               | 24.66                          |
| + 200 c.c. (1.5 % NaOH) for 2 hrs. | 54.33               | 29.20                          |
| + 74 c.c. (2.0 % NaOH) for 2 hrs.  | 45.46               | 28.70                          |

*Influence of Digestion on Total Weight of Dry Matter.*

This experiment was repeated, and the actual weights of total dry matter and crude fibre in the straw before and after heating were determined, allowance being made on the total dry matter for the sodium hydroxide present.

|                                   | Total dry<br>matter<br>gms. | Crude<br>fibre<br>gms. |
|-----------------------------------|-----------------------------|------------------------|
| Original straw ... ..             | 17.86                       | 8.63                   |
| + 74 c.c. (1.5 % NaOH) for 1 hr.  | 18.10                       | 9.02                   |
| + 74 c.c. (1.5 % NaOH) for 2 hrs. | 18.30                       | 9.14                   |
| + 74 c.c. (2.0 % NaOH) for 2 hrs. | 18.48                       | 9.05                   |

The results indicate that there was no loss of dry matter by removal of any volatile material during the heating, and the weight of crude fibre was practically constant.

In all of these experiments it was found that the product obtained when 74 c.c. of the 1.5 per cent. soda solution was used was practically neutral, but that the use of the stronger alkali (2 per cent.) gave an alkaline product.

*Method of preparing the food.*

As a result of the preliminary experiments, the following procedure was adopted in preparing the straw.

(a) *Crude Concentrate:* 24 lbs. of the chopped straw was soaked overnight in a sufficient volume (about 10 gallons) of 1.5 per cent.

aqueous sodium hydroxide in a large galvanised iron tank. The next morning the straw was removed from the liquid, drained and transferred to a large steamer. Steam was blown through the mass until it was all heated up and the steaming was then continued for one hour. When cool the straw was removed from the steamer and drained, any liquid draining away being collected. The material was then pressed in a cheese press, the expressed liquor being collected. The hard cake was broken up, exposed to the air in a thin layer for two days, and then stored in a sack. This process of pressing and drying the material is not necessary for feeding purposes, but was done in order to facilitate sampling during the feeding trial. The liquid which drained away or was pressed out was mixed and its volume measured. A proportionate amount was added each day to the dry treated straw prior to feeding, the mixture thus prepared being the "crude concentrate."

(b) *Washed Concentrate*: The straw was soaked in alkali and steamed as above, and then removed from the steamer and soaked in cold water. This steeping water was drained away and renewed each day for four days, at the end of which time it was only a very pale yellow in colour and neutral to litmus. The material was then drained, pressed and air-dried as above.

*Loss of Dry Matter involved in Process.*

To determine the loss of dry matter by these two processes 75 gm. lots of the straw were subjected to treatment with 1.5 per cent. soda solution in the laboratory, under conditions as nearly comparable as possible with those on the large scale, except that the crude concentrate was only drained and not pressed. The following data are the mean of two tests in each case:

|                                                                            | gms.  |
|----------------------------------------------------------------------------|-------|
| Dry matter in straw at commencement ... ..                                 | 67.20 |
| Dry matter in crude concentrate after allowing for the<br>soda used ... .. | 53.65 |
| Dry matter in "Washed Concentrate" ... ..                                  | 44.70 |

*Percentage Loss of Dry Matter.*

|                                               |        |
|-----------------------------------------------|--------|
| In preparation of "Crude Concentrate" ... ..  | 20.0 % |
| In preparation of "Washed Concentrate" ... .. | 33.5 % |

FEEDING TRIALS.

A preliminary trial with a ewe having shown that she would consume a satisfactory amount of fresh straw or of the "crude concentrate," two wether sheep, weighing about 70 lb. each, were obtained for the

actual digestibility trial. The arrangements for feeding and for collecting the faeces and urine separately were the same as those used by Crowther and Woodman<sup>1</sup> in their work on the digestibility of palm kernel cake.

The food supplies were weighed out for each meal, the quantities being regulated so that complete consumption was effected. Composite samples of each food were made twice weekly, portions being reserved daily in air-tight bottles for the purpose. On these samples moisture determinations were made and from them one composite sample representative of the whole period was prepared for complete analysis.

The fresh faeces were weighed daily and aliquot portions were reserved in air-tight bottles, composite samples being made twice weekly. These composite samples were passed through a small sausage mill and the percentage of moisture was determined in duplicate by drying large samples in an air-oven at 65–70° C. The dry matter was then ground, exposed to the air in thin layers for several days; a composite sample for each period was prepared and on this determinations of moisture, crude and true protein, pepsin-soluble nitrogen, ether extract, crude fibre, ash and sand were made.

The determinations of total nitrogen in the fresh faeces were made twice weekly in triplicate. Comparison with the total nitrogen in the dried faeces indicated a loss in drying and storage ranging from 0.14 to 5.29 per cent. (mean 1.68 per cent.) of the total nitrogen.

The sheep were supplied with water *ad lib.*, no record being kept of the actual consumption.

The general arrangement of the experiment is shown in the following schedule.

| Period No. | Date from and to   | Average daily ration                                                                       | Nutritive ratio |
|------------|--------------------|--------------------------------------------------------------------------------------------|-----------------|
| I          | June 27–July 10    | 114.0 gms. casein<br>+ 341.0 gms. oat straw<br>+ 15.0 gms. salt                            | 1:1.8           |
| II         | July 18–31         | 454.4 gms. linseed cake<br>+ 852.48 gms. treated straw<br>+ 600.0 c.c. of expressed liquid | 1:4.5           |
| III        | August 8–21        | 454.4 gms. linseed cake<br>+ 341.0 gms. straw<br>+ 15.0 gms. salt                          | 1:3.3           |
| IV         | August 29–Sept. 11 | 454.4 gms. linseed cake<br>+ 568.0 gms. "Washed concentrate"<br>+ 15.0 gms. salt           | 1:4.2           |

<sup>1</sup> *Journ. of Agric. Science*, 1917, 8, 429.

The average composition of the feeding stuffs is given in Table I and of the composite samples of faeces for each period in Table II.

Table I. *Average Composition of Feeding Stuffs.*

|                                           |     | Moisture<br>% | Crude<br>protein<br>% | True<br>protein<br>% | Ether<br>extract<br>% | Nitrogen-<br>free<br>extractives<br>% | Crude<br>fibre<br>% | Ash<br>%        |
|-------------------------------------------|-----|---------------|-----------------------|----------------------|-----------------------|---------------------------------------|---------------------|-----------------|
| <i>Period I.</i>                          |     |               |                       |                      |                       |                                       |                     |                 |
| Casein ...                                | ... | 13.55         | 76.04*                | 76.04                | 0.12                  | 2.84                                  | —                   | 7.45<br>(0.46)  |
| Oat straw ...                             | ... | 12.04         | 2.03                  | 1.67                 | 1.58                  | 38.94                                 | 40.40               | 5.01<br>(1.37)  |
| Salt (all periods) ...                    | ... | 3.21          | —                     | —                    | —                     | —                                     | —                   | 96.79<br>(0.05) |
| <i>Period II.</i>                         |     |               |                       |                      |                       |                                       |                     |                 |
| Linseed cake ...                          | ... | 12.69         | 31.70                 | 24.81                | 5.18                  | 36.56                                 | 8.84                | 5.03<br>(0.23)  |
| Treated straw ...                         | ... | 61.42         | 0.37                  | 0.36                 | 0.65                  | 9.98                                  | 24.87               | 2.71<br>(0.23)  |
| Expressed liquor<br>gms. per 100 c.c. ... | ... | 97.15         | 0.23                  | 0.20                 | —                     | 3.23                                  | —                   | 1.21            |
| <i>Period III.</i>                        |     |               |                       |                      |                       |                                       |                     |                 |
| Linseed cake ...                          | ... | 12.64         | 31.72                 | 24.82                | 5.18                  | 36.58                                 | 8.85                | 5.03<br>(0.23)  |
| Oat straw ...                             | ... | 13.47         | 2.05                  | 1.70                 | 1.92                  | 37.54                                 | 40.77               | 4.25<br>(1.86)  |
| <i>Period IV.</i>                         |     |               |                       |                      |                       |                                       |                     |                 |
| Linseed cake ...                          | ... | 12.64         | 31.72                 | 24.82                | 5.18                  | 36.58                                 | 8.85                | 5.03<br>(0.23)  |
| Washed concentrate                        |     | 47.73         | 0.63                  | 0.63                 | 0.76                  | 14.07                                 | 34.73               | 2.08<br>(0.62)  |

The figures in brackets in the last column are the percentages of sand in the feeding stuffs.

\* Pepsin insoluble protein in casein 2.16 %.

In order to arrive at a measure of the "metabolic protein" in the faeces, the amount of pepsin-soluble nitrogen was determined for each composite sample. The results for the four periods give the figure 0.34–0.39 gm. (average 0.365 gm.) per 100 gms. of organic matter digested for Sheep 1, and 0.44–0.54 gm. (average 0.49 gm.) for Sheep 2. These values are slightly lower than the results obtained by Crowther and Woodman<sup>1</sup> and are in fairly close agreement with those found by Kellner<sup>2</sup>.

<sup>1</sup> *loc. cit.*

<sup>2</sup> *Die Ernährung der landw. Nutztiere*, 1 Aufl. p. 32.

*The Digestibility of Straw*Table II. *Average weight and composition of Faeces.*

| <i>Sheep 1.</i>                  |                  |                   |                    |                   |
|----------------------------------|------------------|-------------------|--------------------|-------------------|
|                                  | Period I<br>gms. | Period II<br>gms. | Period III<br>gms. | Period IV<br>gms. |
| Weight of fresh faeces daily ... | 297.5            | 531.8             | 605.8              | 488.9             |
| Weight of dry matter daily ...   | 157.8            | 200.2             | 252.5              | 187.7             |

*Composition of Dry Matter.*

|                                   | %     | %     | %     | %     |
|-----------------------------------|-------|-------|-------|-------|
| Crude protein* ... ..             | 7.73  | 16.55 | 10.61 | 16.47 |
| Ether extract ... ..              | 1.92  | 3.09  | 2.32  | 2.87  |
| Nitrogen-free extractives ...     | 47.66 | 36.01 | 43.44 | 33.06 |
| Crude fibre ... ..                | 31.80 | 30.43 | 33.04 | 33.56 |
| Ash† ... ..                       | 10.89 | 13.92 | 10.59 | 14.04 |
| * Including true protein ...      | 6.87  | 15.07 | 9.89  | 15.60 |
| * Including pepsin-insol. protein | 4.59  | 10.16 | 6.92  | 9.93  |
| † Including sand ... ..           | 3.17  | 3.68  | 2.65  | 3.33  |

*Sheep 2.*

|                                  | gms.  | gms.  | gms.  | gms.  |
|----------------------------------|-------|-------|-------|-------|
| Weight of fresh faeces daily ... | 404.5 | 709.9 | 863.3 | 575.1 |
| Weight of dry matter daily ...   | 181.4 | 206.2 | 276.3 | 202.0 |

*Composition of Dry Matter.*

|                                   | %     | %     | %     | %     |
|-----------------------------------|-------|-------|-------|-------|
| Crude protein* ... ..             | 7.70  | 17.36 | 11.58 | 17.02 |
| Ether extract ... ..              | 1.67  | 2.93  | 1.96  | 2.25  |
| Nitrogen-free extractives ...     | 47.08 | 37.25 | 42.11 | 33.18 |
| Crude fibre ... ..                | 33.05 | 27.82 | 33.55 | 33.62 |
| Ash† ... ..                       | 10.41 | 14.64 | 10.80 | 13.93 |
| * Including true protein ...      | 6.74  | 15.48 | 10.43 | 15.69 |
| * Including pepsin-insol. protein | 4.25  | 10.39 | 6.60  | 9.67  |
| † Including sand ... ..           | 2.69  | 3.74  | 2.46  | 3.31  |

*Digestibility of original Oat Straw.*

We may now consider the results obtained in the different periods of the experiment, taking first Period I, in which oat straw and casein were fed. Commercial casein was added to the oat straw in order to supply the necessary protein to the ration, it being chosen as the simplest digestible protein obtainable in bulk and likely to contain little or no crude fibre or nitrogen-free extractives as impurities. Apart from protein, the sample used contained only 3 per cent. of organic matter, most of which consisted of nitrogen-free extractives, which were assumed to be digestible. Determinations *in vitro* showed that the material contained 2.16 per cent. of pepsin-insoluble protein, and, for

the purposes of calculation, this value was taken as a measure of the digestibility of the casein. The essential data and the digestion coefficients deduced therefrom are summarised in Table III.

Table III. *Period I (Oat Straw and Casein).*

Daily ration: 114 gms. casein + 341 gms. oat straw + 15 gms. salt.

|                                                      | <i>Sheep 1.</i>       |                     |                      |                    |                   |                    |                                |                  |  |  |
|------------------------------------------------------|-----------------------|---------------------|----------------------|--------------------|-------------------|--------------------|--------------------------------|------------------|--|--|
|                                                      | Total dry matter gms. | Organic matter gms. | Ash (sand free) gms. | Crude protein gms. | True protein gms. | Ether extract gms. | Nitrogen-free extractives gms. | Crude fibre gms. |  |  |
| Consumed:                                            |                       |                     |                      |                    |                   |                    |                                |                  |  |  |
| Casein ...                                           | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| Oat straw ...                                        | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| Salt ...                                             | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| Total ...                                            | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| Voided:                                              |                       |                     |                      |                    |                   |                    |                                |                  |  |  |
| Total ...                                            | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| From casein ...                                      | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| From straw ...                                       | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| Digested from straw ...                              | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| Digestion coefficients of oat straw %                | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| <i>Sheep 2.</i>                                      |                       |                     |                      |                    |                   |                    |                                |                  |  |  |
| Consumed: (as above)                                 |                       |                     |                      |                    |                   |                    |                                |                  |  |  |
| Voided:                                              |                       |                     |                      |                    |                   |                    |                                |                  |  |  |
| Total ...                                            | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| From casein ...                                      | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| From straw ...                                       | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| Digested from straw ...                              | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| Digestion coefficients of oat straw %                | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |
| <i>Average digestion coefficients of oat straw %</i> | ...                   | ...                 | ...                  | ...                | ...               | ...                | ...                            | ...              |  |  |

\* The average corrected digestion coefficients of crude and true protein respectively from the two sheep were 27.5% and 12.5%. The coefficient obtained by direct treatment of the finely ground straw with pepsin-HCl was 51.4%.

*The Digestibility of Straw*

The average coefficients agree fairly well with the following averages of nine experiments as given by Kellner.

|                           |     | Percentage digestibility |         |
|---------------------------|-----|--------------------------|---------|
|                           |     | Range of variation       | Average |
|                           |     | %                        | %       |
| Organic matter ...        | ... | 40-51                    | 46      |
| Crude protein ...         | ... | 21-29                    | 23      |
| Ether extract ...         | ... | 21-41                    | 36      |
| Nitrogen-free extractives |     | 29-52                    | 39      |
| Crude fibre ...           | ... | 47-73                    | 55      |

On the whole the sample of oat straw used was above the average digestibility as indicated by Kellner's figures.

Owing to the fact that the sheep did not appear to be doing well upon this ration it was considered advisable to substitute linseed cake for the casein, as a source of protein in the other periods. It was, in consequence, necessary to introduce an extra period (Period III) into the experiment for the purpose of determining the digestibility of the linseed cake. Both sheep showed great improvement due to this change on to linseed cake.

*Digestibility of Linseed Cake.*

The results of Period III may be considered next in order to arrive at the digestibility coefficients of the linseed cake. These are summarised in Table IV, which indicates also how by deducting the contribution of the oat straw to the faeces as ascertained in Period I, the digestibility of the linseed cake is arrived at.

The concordance between the two sets of results is very good. The average results agree very well with the following averages of fourteen experiments as given by Kellner.

|                           |     | Percentage digestibility |         |
|---------------------------|-----|--------------------------|---------|
|                           |     | Range of variation       | Average |
|                           |     | %                        | %       |
| Organic matter ...        | ... | 74-88                    | 79      |
| Crude protein ...         | ... | 80-90                    | 86      |
| Ether extract ...         | ... | 86-97                    | 92      |
| Nitrogen-free extractives |     | 60-96                    | 78      |
| Crude fibre ...           | ... | 0-92                     | (32)    |

So far as digestibility is concerned little fault could be found with the linseed cake used in our experiment.

Table IV. *Period III* (Oat Straw and Linseed Cake).

Daily ration: 454.4 gms. linseed cake + 341.0 gms. oat straw + 15 gms. salt.

| Sheep 1.                                                                |                  |                |                 |               |              |               |                           |             |        |
|-------------------------------------------------------------------------|------------------|----------------|-----------------|---------------|--------------|---------------|---------------------------|-------------|--------|
|                                                                         | Total dry matter | Organic matter | Ash (sand free) | Crude protein | True protein | Ether extract | Nitrogen free extractives | Crude fibre |        |
|                                                                         | gms.             | gms.           | gms.            | gms.          | gms.         | gms.          | gms.                      | gms.        |        |
| Consumed:                                                               |                  |                |                 |               |              |               |                           |             |        |
| Linseed cake                                                            | ...              | 396.96         | 374.10          | 21.83         | 112.79       | 23.54         | 166.21                    | 40.21       |        |
| Oat straw                                                               | ...              | 295.07         | 280.55          | 8.17          | 6.99         | 5.80          | 127.97                    | 139.04      |        |
| Salt                                                                    | ...              | 14.52          | —               | 14.51         | —            | —             | —                         | —           |        |
| Total                                                                   | ...              | 706.55         | 654.65          | 44.51         | 118.59       | 30.09         | 294.18                    | 179.25      |        |
| Voided:                                                                 |                  |                |                 |               |              |               |                           |             |        |
| Total                                                                   | ...              | 232.51         | 225.77          | 20.05         | 26.79        | 21.98         | 109.69                    | 83.43       |        |
| From oat straw (calc. from Period I)                                    | ...              | 132.84         | 136.91          | 8.01          | 4.83*        | 4.87*         | 72.43                     | 50.61       |        |
| From linseed cake                                                       | ...              | 99.67          | 88.86           | 12.04         | 21.96        | 20.11         | 37.26                     | 32.82       |        |
| Digested from linseed cake                                              | ...              | 297.29         | 285.24          | 9.79          | 122.18       | 92.68         | 21.37                     | 128.95      | 7.39   |
| Digestion coefficient of linseed cake <sup>65</sup>                     | ...              | 74.90          | 76.20           | 44.80         | 84.80        | 82.20         | 90.80                     | 18.40       |        |
| Sheep 2.                                                                |                  |                |                 |               |              |               |                           |             |        |
|                                                                         | Total            | Organic matter | Ash (sand free) | Crude protein | True protein | Ether extract | Nitrogen free extractives | Crude fibre |        |
|                                                                         | gms.             | gms.           | gms.            | gms.          | gms.         | gms.          | gms.                      | gms.        |        |
| Consumed:                                                               |                  |                |                 |               |              |               |                           |             |        |
| Linseed cake                                                            | ...              | 276.31         | 246.47          | 23.04         | 32.01        | 28.82         | 5.42                      | 116.34      | 92.70  |
| Oat straw                                                               | ...              | 176.15         | 158.79          | ?             | 5.30*        | 5.34*         | 3.69                      | 82.28       | 60.48  |
| Total                                                                   | ...              | 452.46         | 405.26          | ?             | 37.31        | 34.16         | 9.11                      | 198.62      | 153.18 |
| From linseed cake                                                       | ...              | 100.16         | 87.08           | ?             | 26.71        | 23.48         | 1.73                      | 34.06       | 32.22  |
| Digested from linseed cake                                              | ...              | 296.80         | 286.42          | ?             | 117.43       | 89.31         | 21.81                     | 132.15      | 7.36   |
| Digestion coefficient of linseed cake <sup>66</sup>                     | ...              | 74.80          | 76.69           | ?             | 81.59        | 79.29         | 92.69                     | 79.50       | 19.90  |
| From oat straw                                                          | ...              | 176.15         | 158.79          | ?             | 5.30*        | 5.34*         | 3.69                      | 82.28       | 60.48  |
| Digested from oat straw                                                 | ...              | 74.80          | 76.40           | (44.80)       | 83.29        | 80.70         | 91.70                     | 78.60       | 19.20  |
| Digestion coefficient of oat straw <sup>67</sup>                        | ...              | ...            | ...             | ...           | ...          | ...           | ...                       | ...         | ...    |
| * These figures are calculated from the corrected values for oat straw. |                  |                |                 |               |              |               |                           |             |        |

\* These figures are calculated from the corrected values for oat straw.



*The Digestibility of Straw**Corrected Digestibility of Protein.*

|                                                            | <i>Sheep 1.</i> |              | <i>Sheep 2.</i> |              |
|------------------------------------------------------------|-----------------|--------------|-----------------|--------------|
|                                                            | Crude protein   | True protein | Crude protein   | True protein |
| Total pepsin-insol. protein voided gms.                    | 17.47           | 17.47        | 18.16           | 18.16        |
| Deduct for oat straw gms. ... ..                           | 4.83            | 4.87         | 5.30            | 5.34         |
| Pepsin-insol. protein voided from linseed cake gms. ... .. | 12.64           | 12.60        | 12.86           | 12.82        |
| Digestion coefficients % ... ..                            | 91.20           | 88.80        | 91.10           | 88.60        |

Average: Crude protein 91.2 %\*; True protein 88.7 %.

\* Coefficient determined by treatment of the cake with pepsin-HCl was 92.0 %.

*Digestibility of "Crude Concentrate."*

Considering now the records of Period II in which the crude concentrate was fed along with linseed cake, these are summarised in Table V. For the purpose of calculating the digestibility coefficients the treated straw and expressed liquor are combined as one foodstuff, since, in ordinary practice the liquid would be left in the straw and not pressed out prior to feeding.

In this period it was very difficult to get accurate collections of the faeces, more particularly from Sheep 2, owing to the fact that the faeces were soft and tended to adhere to the collection bag. In view of this fact, the agreement between the records of the two animals must be considered as good throughout.

It was not possible to obtain results for the digestibility coefficients of the protein in the crude concentrate, since, after making due allowance for the metabolic nitrogen and undigested nitrogen from the linseed cake in the faeces, it was found that for both sheep apparently more protein was voided than was fed in the straw. Similarly it was not possible to arrive at an accurate figure for the pepsin-insoluble nitrogen in the crude concentrate itself as in every case, after taking all precautions, the results obtained were higher than those for the total nitrogen in the straw. As a result of treatment with the alkali at steam temperature, the straw had probably undergone some change in its physical character which caused a very marked increase in its absorptive capacity, some of the nitrogen of the pepsin being apparently retained. These remarks probably apply also to the faeces from this period, and consequently the pepsin-insoluble protein results for the faeces are not correct. It is possible that some of the digested protein of the linseed cake may have been retained by the undigested straw and excreted along with it, thus giving rise to a further error. It should be noted that

the amount of protein contributed by the treated straw to the ration is only 3 per cent. of the total protein in the ration.

Table V. *Period II* (linseed cake + "Crude Concentrate").

Daily ration: 454.4 gms. linseed cake + 852.48 gms. treated straw + 600 c.c. expressed liquor.

| <i>Sheep 1.</i>                                    |                  |                |                 |               |              |               |                           |             |  |
|----------------------------------------------------|------------------|----------------|-----------------|---------------|--------------|---------------|---------------------------|-------------|--|
|                                                    | Total dry matter | Organic matter | Ash (sand free) | Crude protein | True protein | Ether extract | Nitrogen-free extractives | Crude fibre |  |
|                                                    | gms.             | gms.           | gms.            | gms.          | gms.         | gms.          | gms.                      | gms.        |  |
| Consumed:                                          |                  |                |                 |               |              |               |                           |             |  |
| Linseed cake                                       | 396.74           | 373.88         | 21.82           | 144.05        | 112.73       | 23.53         | 166.11                    | 40.19       |  |
| Crude concentrate                                  | 359.91           | 326.59         | 28.41           | 4.57          | 4.31         | 5.53          | 104.50                    | 211.99      |  |
| Total                                              | 756.65           | 700.47         | 50.23           | 148.62        | 117.04       | 29.06         | 270.61                    | 252.18      |  |
| Voided:                                            |                  |                |                 |               |              |               |                           |             |  |
| Total                                              | 200.17           | 172.31         | 20.50           | 33.13         | 30.17        | 6.19          | 72.08                     | 60.91       |  |
| From linseed cake (calc. from Period III)          | 99.58            | 88.98          | 12.94           | 21.89         | 20.06        | 2.16          | 37.21                     | 32.70       |  |
| From crude concentrate                             | 100.59           | 83.33          | 8.46            | 11.24         | 10.11        | 4.03          | 34.87                     | 28.12       |  |
| Digested from crude concentrate                    | 250.32           | 243.26         | 19.05           | (-6.87)       | (-5.80)      | 1.50          | 69.63                     | 183.87      |  |
| Digestion coefficients of crude concentrate        | 71.80            | 74.50          | 70.20           | ?             | ?            | 27.10         | 66.60                     | 86.70       |  |
| <i>Sheep 2.</i>                                    |                  |                |                 |               |              |               |                           |             |  |
|                                                    | Total dry matter | Organic matter | Ash (sand free) | Crude protein | True protein | Ether extract | Nitrogen-free extractives | Crude fibre |  |
|                                                    | gms.             | gms.           | gms.            | gms.          | gms.         | gms.          | gms.                      | gms.        |  |
| Consumed:                                          |                  |                |                 |               |              |               |                           |             |  |
| Linseed cake                                       | 396.74           | 373.88         | 21.82           | 144.05        | 112.73       | 23.53         | 166.11                    | 40.19       |  |
| Crude concentrate                                  | 359.91           | 326.59         | 28.41           | 4.57          | 4.31         | 5.53          | 104.50                    | 211.99      |  |
| Total                                              | 756.65           | 700.47         | 50.23           | 148.62        | 117.04       | 29.06         | 270.61                    | 252.18      |  |
| Voided:                                            |                  |                |                 |               |              |               |                           |             |  |
| Total                                              | 200.17           | 172.31         | 20.50           | 33.13         | 30.17        | 6.19          | 72.08                     | 60.91       |  |
| From linseed cake (calc. from Period III)          | 99.58            | 88.98          | 12.94           | 21.89         | 20.06        | 2.16          | 37.21                     | 32.70       |  |
| From crude concentrate                             | 100.59           | 83.33          | 8.46            | 11.24         | 10.11        | 4.03          | 34.87                     | 28.12       |  |
| Digested from crude concentrate                    | 250.32           | 243.26         | 19.05           | (-6.87)       | (-5.80)      | 1.50          | 69.63                     | 183.87      |  |
| Digestion coefficients of crude concentrate        | 71.80            | 74.50          | 70.20           | ?             | ?            | 27.10         | 66.60                     | 86.70       |  |
| Consumed: (as above)                               |                  |                |                 |               |              |               |                           |             |  |
| Voided:                                            |                  |                |                 |               |              |               |                           |             |  |
| Total                                              | 200.17           | 172.31         | 20.50           | 33.13         | 30.17        | 6.19          | 72.08                     | 60.91       |  |
| From linseed cake (calc. from Period III)          | 99.58            | 88.98          | 12.94           | 21.89         | 20.06        | 2.16          | 37.21                     | 32.70       |  |
| From crude concentrate                             | 100.59           | 83.33          | 8.46            | 11.24         | 10.11        | 4.03          | 34.87                     | 28.12       |  |
| Digested from crude concentrate                    | 250.32           | 243.26         | 19.05           | (-6.87)       | (-5.80)      | 1.50          | 69.63                     | 183.87      |  |
| Digestion coefficients of crude concentrate        | 71.80            | 74.50          | 70.20           | ?             | ?            | 27.10         | 66.60                     | 86.70       |  |
| Accum. digestion coefficients of crude concentrate | 71.90            | 73.70          | 70.20           | ?             | ?            | 24.70         | 62.90                     | 87.40       |  |

## The Digestibility of Strain

## Digestibility of "Washed Concentrate."

The records of Period IV, in which the "washed concentrate" was fed along with linseed cake, are summarised in Table VI.

Table VI. *Period IV (Linseed Cake + "Washed Concentrate")*,  
Daily ration: 454.4 gms. linseed cake + 56.80 gms. washed concentrate + 15 gms. salt.

| <i>Sheep 1.</i>                                        |                       |                     |                     |                    |                   |                    |                                |                  |        |
|--------------------------------------------------------|-----------------------|---------------------|---------------------|--------------------|-------------------|--------------------|--------------------------------|------------------|--------|
| Consumed:                                              | Total dry matter gms. | Organic matter gms. | Ash (and free) gms. | Crude protein gms. | True protein gms. | Ether extract gms. | Nitrogen-free extractives gms. | Crude fibre gms. |        |
| Linseed cake ...                                       | ...                   | 396.96              | 374.10              | 21.88              | 144.14            | 112.79             | 23.54                          | 166.21           | 40.21  |
| Washed concentrate ...                                 | ...                   | 296.89              | 285.05              | 8.31               | 3.58              | 3.58               | 4.30                           | 79.88            | 197.29 |
| Salt ...                                               | ...                   | 14.52               | —                   | 14.51              | —                 | —                  | —                              | —                | —      |
| Total ...                                              | ...                   | 708.37              | 659.15              | 44.65              | 147.72            | 116.37             | 27.84                          | 246.09           | 237.50 |
| Voided:                                                |                       |                     |                     |                    |                   |                    |                                |                  |        |
| Total ...                                              | ...                   | 187.68              | 161.33              | 20.10              | 30.91             | 29.27              | 5.39                           | 62.05            | 62.98  |
| From linseed cake (calc. from Period III) ...          | ...                   | 99.67               | 88.86               | 12.04              | 21.96             | 20.11              | 2.17                           | 37.25            | 32.82  |
| From washed concentrate ...                            | ...                   | 88.01               | 72.47               | 8.06               | 8.95              | 9.16               | 3.22                           | 24.79            | 30.16  |
| Digested from washed concentrate ...                   | ...                   | 208.88              | 212.58              | 0.25               | (-5.37)           | (-5.58)            | 1.08                           | 55.09            | 167.13 |
| Digestion coefficients of washed concentrate %         | ...                   | 70.40               | 74.60               | 3.00               | ?                 | ?                  | 25.10                          | 68.90            | 84.70  |
| <i>Sheep 2.</i>                                        |                       |                     |                     |                    |                   |                    |                                |                  |        |
| Consumed: (as above)                                   |                       |                     |                     |                    |                   |                    |                                |                  |        |
| Voided:                                                |                       |                     |                     |                    |                   |                    |                                |                  |        |
| Total ...                                              | ...                   | 201.99              | 173.85              | 21.45              | 34.33             | 31.68              | 4.54                           | 67.02            | 67.91  |
| From linseed cake (calc. from Period III) ...          | ...                   | 100.16              | 87.67               | ?                  | 26.71             | 23.48              | 1.73                           | 34.06            | 32.22  |
| From washed concentrate ...                            | ...                   | 101.83              | 86.17               | ?                  | 7.67              | 8.20               | 2.81                           | 32.96            | 35.69  |
| Digested from washed concentrate ...                   | ...                   | 195.06              | 198.83              | ?                  | (-4.09)           | (-4.62)            | 1.40                           | 46.92            | 161.60 |
| Digestion coefficients of washed concentrate %         | ...                   | 65.70               | 69.80               | ?                  | ?                 | ?                  | 33.60                          | 58.70            | 81.90  |
| Average digestion coefficients of washed concentrate % | ...                   | 68.10               | 72.20               | (3.00)             | ?                 | ?                  | 29.90                          | 63.80            | 83.30  |

On the whole the records of the two sheep in this period show a fairly close agreement, although not so close as in Period II. Again it was not possible to obtain results for the digestibility coefficients of the protein in the "washed concentrate." The result obtained *in vitro* was 9.7 per cent. This is probably low but indicates that, as might be expected, a considerable proportion of the digestible protein in the original oat straw had been removed by the steaming with 1.5 per cent. soda solution.

#### Nitrogen Balance.

As the urine was collected and measured from each sheep throughout the experiment, and bi-weekly nitrogen determinations made on composite samples, it is possible to give a complete survey of the utilisation of the food nitrogen, as shown in Table VII.

Table VII. *Nitrogen Balance.*

| Period | Nature of ration                  | Sheep | Nitrogen consumed<br>(av. per day)<br>gms. | Nitrogen excreted<br>(averages per day) |                  |               | Nitrogen retained (+) or lost (-) by sheep<br>(av. per day)<br>gms. |
|--------|-----------------------------------|-------|--------------------------------------------|-----------------------------------------|------------------|---------------|---------------------------------------------------------------------|
|        |                                   |       |                                            | In faeces<br>gms.                       | In urine<br>gms. | Total<br>gms. |                                                                     |
| I      | Casein + Oat straw                | 1     | 14.67                                      | 1.97                                    | 14.30            | 16.27         | -1.60                                                               |
|        |                                   | 2     | 14.67                                      | 2.30                                    | 16.04            | 18.34         | -3.67                                                               |
| II     | Linseed cake + Crude concentrate  | 1     | 23.78                                      | 5.32                                    | 14.10            | 19.42         | +4.36                                                               |
|        |                                   | 2     | 23.78                                      | 5.85                                    | 13.70            | 19.55         | +4.23                                                               |
| III    | Linseed cake + Oat straw          | 1     | 24.18                                      | 4.53                                    | 19.07            | 23.60         | +0.58                                                               |
|        |                                   | 2     | 24.18                                      | 5.30                                    | 18.34            | 23.64         | +0.54                                                               |
| IV     | Linseed cake + Washed concentrate | 1     | 23.64                                      | 4.97                                    | 15.15            | 20.12         | +3.52                                                               |
|        |                                   | 2     | 23.64                                      | 5.61                                    | 14.40            | 20.01         | +3.63                                                               |

It will be observed that the maximum retention of nitrogen occurred with both sheep in Periods II and IV when the nitrogen consumed averaged about 23.7 gms. per day; when this nitrogen was increased slightly (Period III) there was a considerable diminution in the nitrogen retention. In Period I where the nitrogen consumption dropped to well below 20 gms. per day there was a decided negative nitrogen balance with both sheep.

In view of the fact that straw contains a considerable proportion of pentosans, it was thought of interest to follow the excretion of pentoses in the urine throughout the experiment. Accordingly a composite sample was prepared each week, toluene being used as a preservative, and the pentoses present were estimated therein by Tollens' method. The results, as given below, show that the result of the treatment of the straw with soda was to throw up the amount of pentoses excreted, especially in

the case of the crude concentrate, as indicated by comparison of the results from Periods II and III.

| Period | Total pentoses excreted in urine<br>per period |                 |
|--------|------------------------------------------------|-----------------|
|        | Sheep 1<br>gms.                                | Sheep 2<br>gms. |
| I      | 3.57                                           | 0.98            |
| II     | 6.09                                           | 5.34            |
| III    | 2.92                                           | 3.38            |
| IV     | 3.06                                           | 4.30            |

The increased excretion of pentoses apparently did not interfere with the general well-being of the sheep.

In conclusion, I desire to express my indebtedness to Prof. Charles Crowther for initiating this work and making many valuable suggestions during its progress and in the subsequent compilation of this paper.

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# DIGESTIBILITY OF PEAT MOSS AFTER TREATMENT WITH ACID.

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IN connection with the experiments described in the foregoing paper the opportunity was taken of determining the digestibility of a proprietary product suggested for use as a feeding-stuff, which was made by subjecting finely-shredded peat moss to the action of hydrochloric acid gas, and subsequently expelling the latter from the residual product. By this treatment appreciable quantities of reducing sugars are produced in the peat moss, amounting in some cases, it is claimed, to 15 or even 20 per cent.

For the purpose of the digestion trial a further period (Period V) was added to the experiment described in the foregoing paper, in which period the sheep received per head daily the following ration:

|            |                   |
|------------|-------------------|
| 284.0 gms. | Linseed cake      |
| 284.0 "    | Treated peat moss |
| 227.2 "    | Oat straw         |
| 15.0 "     | Salt              |

The linseed cake was ground to meal and mixed with the peat moss just before each meal was given.

The composition of the various foods used was as follows:

|              | Moisture<br>% | Crude<br>protein<br>" | True<br>protein<br>% | Ether<br>extract<br>" | Nitrogen-<br>free<br>extractives<br>" | Crude<br>fibre<br>" | Ash<br>"       |
|--------------|---------------|-----------------------|----------------------|-----------------------|---------------------------------------|---------------------|----------------|
| Linseed cake | 11.98         | 31.55                 | 24.36                | 6.36                  | 35.54                                 | 9.39                | 5.27<br>(0.89) |
| Peat moss    | 22.57         | 4.87                  | 4.24                 | 3.44                  | 42.48                                 | 20.64               | 6.00<br>(1.02) |
| Oat straw    | 14.57         | 2.24                  | 1.85                 | 1.68                  | 38.29                                 | 38.11               | 5.11<br>(2.13) |

*Digestibility of Peat Moss*

The average composition of the composite sample of faeces for the period is given in the following table:

|                                  | Sheep 1 | Sheep 2 |
|----------------------------------|---------|---------|
|                                  | gms.    | gms.    |
| Weight of fresh faeces daily ... | 785.3   | 779.3   |
| Weight of dry matter daily ...   | 337.3   | 346.9   |

*Composition of Dry Matter.*

|                                      | %     | %     |
|--------------------------------------|-------|-------|
| Crude protein* ... ..                | 10.66 | 11.51 |
| Ether extract ... ..                 | 3.23  | 2.75  |
| Nitrogen-free extractives... ..      | 50.86 | 49.56 |
| Crude fibre ... ..                   | 26.87 | 27.22 |
| Ash† ... ..                          | 8.38  | 8.96  |
| * Including true protein ... ..      | 10.16 | 10.76 |
| * Including pepsin-insoluble protein | ?     | ?     |
| † Including sand ... ..              | 2.64  | 2.55  |

## DIGESTIBILITY OF THE TREATED PEAT MOSS.

This period is comparable with Period III of the preceding experiment, except that a portion of the oat straw and of the linseed cake was replaced by the treated peat moss. The latter was introduced gradually into the ration, the amount being increased until equal weights of peat moss and linseed cake (ground to meal) were being fed.

## CORRECTED DIGESTIBILITY OF PROTEIN.

Excluding the results for the "Ether Extract" the records of the two sheep are in fairly close agreement throughout. The digestibility of the peat moss is extremely low even as compared with the original untreated oat straw.

Attempts to arrive at an accurate figure for the pepsin-insoluble nitrogen in the faeces from either sheep were not successful, as, in every case, the values obtained for pepsin-insoluble nitrogen in the faeces were equal to or even slightly higher than the value for total nitrogen. The same remark applies to determinations of pepsin-insoluble nitrogen in the peat moss itself. Apparently both the peat moss and the faeces resulting from feeding it exert a strong absorptive action for nitrogenous substances, since prolonging the pepsin-HCl digestion to four days and washing the insoluble residue for a long time did not appreciably lower the values for pepsin-insoluble nitrogen.

If we assume the protein to be one-third digestible and further assume an "efficiency factor" ("Wertigkeit") of 80 per cent. we arrive at a starch equivalent (production) of 15.4 *per cent.* for the treated peat moss. This although a sensible advance upon the value of raw peat moss still leaves it well within the class of low-grade fodders.

Sheep 1.

|                                                                   | Total dry<br>matter<br>gms. | Organic<br>matter<br>gms. | Ash (sand<br>free)<br>gms. | Crude<br>protein<br>gms. | True<br>protein<br>gms. | Ether<br>extract<br>gms. | Nitrogen-free<br>extractives<br>gms. | Crude<br>fat<br>gms. |
|-------------------------------------------------------------------|-----------------------------|---------------------------|----------------------------|--------------------------|-------------------------|--------------------------|--------------------------------------|----------------------|
| Consumed:                                                         |                             |                           |                            |                          |                         |                          |                                      |                      |
| Oat straw                                                         | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Linseed cake                                                      | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Peat moss                                                         | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Salt                                                              | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Total                                                             | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Voided:                                                           |                             |                           |                            |                          |                         |                          |                                      |                      |
| Total                                                             | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| From oat straw plus linseed cake<br>(calc. from Periods I and II) | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| From peat moss                                                    | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Digested from peat moss                                           | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Digestion coefficients of peat moss                               | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |

Sheep 2.

|                                                                   | Total dry<br>matter<br>gms. | Organic<br>matter<br>gms. | Ash (sand<br>free)<br>gms. | Crude<br>protein<br>gms. | True<br>protein<br>gms. | Ether<br>extract<br>gms. | Nitrogen-free<br>extractives<br>gms. | Crude<br>fat<br>gms. |
|-------------------------------------------------------------------|-----------------------------|---------------------------|----------------------------|--------------------------|-------------------------|--------------------------|--------------------------------------|----------------------|
| Consumed: (as above)                                              |                             |                           |                            |                          |                         |                          |                                      |                      |
| Voided:                                                           |                             |                           |                            |                          |                         |                          |                                      |                      |
| Total                                                             | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| From oat straw plus linseed cake<br>(calc. from Periods I and II) | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| From peat moss                                                    | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Digested from peat moss                                           | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Digestion coefficients of peat moss                               | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |
| Average digestion coefficients of peat<br>moss                    | ...                         | ...                       | ...                        | ...                      | ...                     | ...                      | ...                                  | ...                  |

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